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ELECTRONICS RESEARCH LABORATORY

TECHNICAL REPORT

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LAND NAVIGATION IN NORTH WEST AUSTRALIA UTILIZING DIFFERENTIAL OMEGA

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S U M M A R Y

(U) Field trials were carried out in July/August 1980 to test the efficacy of Differential Omega for land navigation in the Pilbara region of Western Australia. To this end a base station was set up in Onslow and movements undertaken between the Onslow trig. station and similar survey marks at ranges of up to 400 km. This Technical Report describes the nature of the exercise and discusses the results obtained.

(U) Additionally, the diurnal phases of several Omega transmissions were recorded simultaneously in Perth and Adelaide during the return of the equipment to Salisbury. These records are subjected to a brief examination.

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1. INTRODUCTION

During the preparation of the Task Plan 'VLF for Field Fixing: Task ARM 76/110' early in 1977, it was envisaged that it would be necessary to carry out Differential Omega trials in certain specific regions outside South Australia. These included the Pilbara region of Western Australia where it was supposed that a transequatorial anomaly might be evident in transmissions from Omega Japan. Accordingly, an exercise in this general area was included in the Task Plan. *

(U) In mid 1978, after experience had been gained in the fielding of Differential Omega trials within a range of several hundred kilometres from Salisbury, plans were laid for the Pilbara operation. A background study was undertaken to find a suitable base for the exercise, bearing in mind the requirements of accommodation for personnel and equipment, a continuous mains power supply, space for erection of communication antennae and availability of a local trig. station. After a consideration of various airport sites along the north west coast it was decided, on the advice of contacts within the Department of Transport, to seek a town site, and to this end negotiations were opened with the Shire Clerk of the West Pilbara Shire Council who, in due course, advised that all requirements could be met by Council-sponsored accommodation in Onslow.

(U) The Department of National Mapping subsequently supplied large-scale maps of the Pilbara region together with details of all trig. stations within 500 km of Onslow; on this basis a schedule of movements was drawn up covering a wide variety of terrain.

(U) It had long been evident that the resources of Navigation Section, Radio Group, would be inadequate, in terms of man power, to meet the requirements of the trial, and assistance had been sought from Army, within both a personnel and logistic context. Approval was given in September 1979 for the secondment to the trial of two personnel from SAS Regiment. It was planned that these soldiers would drive the ERL navigation vehicle and a 2 1/2 tonne army truck from Perth to Onslow, assist in the conduct of the trial, and return the vehicles to Perth at the conclusion of the exercise. The truck would carry boxed equipment, communications masts and tackle and a considerable quantity of ancillary gear.

(U) A field reconnaissance was carried out by the author in May 1980, some six weeks before the scheduled commencement of the trial. This revealed that considerable difficulty could be experienced in locating existing survey stations in remote areas. Thus, although the Onslow station was readily accessible (and was, at the time, the site of a UHF transponder operated by Offshore Navigation Incorporated for a marine seismic survey) attempts to locate a survey mark some 50 km from Onslow were all but frustrated by the ravages which time had effected since the associated access data had last been revised. Since there was a distinct possibility that this would prove to be not an isolated case and that, in consequence, a new schedule of movements would have to be drawn up to fit, in effect, a greatly contracted time scale, the author was led on his return to seek advice from the Senior Surveyor, Department of Administrative Services, Adelaide. The latter suggested that his opposite number in Perth be approached with a request that additional trig. stations be established at roadside locations and at appropriate intervals throughout the entire region.

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* The Task was re-designated DST 77/112 - VLF LAND NAV in November 1977 and replaced by DST 80/045 - VLF LAND NAV STAGE B in July 1980.

(U) As a result of such representations a field survey party was despatched from Perth on 9 June but was forced to return in mid June with the job incomplete because of unprecedented rainfall south of Onslow. Most roads in the district were impassable and floodwaters had cut the spur road between Onslow and the North West Coastal Highway at a distance of 25 km from the town. This link was not restored until mid-July. The survey team returned to the region in early July and was still at work south of Onslow while the navigation exercise was in progress to the north.

(U) The Electronics Research Laboratory team comprising R.S. Edgar and A.R. Padgham arrived in Onslow by air on 16 July while the SAS personnel - R.J. Bower and W.M. Dangerfield of 152 Sig. Squadron - reached Onslow by road on 18 July. The base station was set up and checked out during the following ten days and the trial proceeded throughout the remainder of July and August. In the second week of September the base station equipment was dismantled and boxed, and returned to Perth together with the navigation vehicle. The latter was held in Perth in an operating condition while the base equipment was despatched to Adelaide and set up in Defence Research Centre Salisbury. Simultaneous recordings of diurnal phase were made in Perth and Adelaide on several Omega frequencies during the following week, after which the navigation vehicle was returned to Defence Research Centre Salisbury.

2. TRIALS PROCEDURE AND MOVEMENTS

As in the case of trials previously conducted in South Australia (Ref. 1) measurements were made of the increments of signal phase of several Omega transmissions during the passage of the navigation vehicle from one trig. station to the next, due allowance being made for that component which derived from propagational variation, as monitored at the base station. Phase changes were transformed into incremental radial distance from the Omega transmitters by the adoption of an appropriate phase velocity of transmission, and the results compared with computed values based on the known latitude/longitude of the transmitters and the trig. stations.

(U) All movements originated and ended at the Onslow survey mark (R299). This mark was located on a sand hill overlooking the sea and about 500 m from the Shire Offices, where the base station was located. Prior to each movement the relative epoch of the base and mobile clocks (Rubidium frequency standards) was measured at the base station; the vehicle then proceeded to R299 for initialisation. On return, a further epoch check was carried out. Any non-closure of the traverse could then, ideally, be correlated with clock slip, and allowance made for this throughout the movement on the assumption that linear time interpolation was permissible.

(U) Since Omega signals were recorded continuously on tape at base and in the vehicle for the duration of each movement, the records obtained during night time stop-overs away from base made possible a determination of the degree of ionospheric de-correlation obtaining between Onslow and the remote site during the hours of darkness and, consequently, the navigational errors likely to be encountered during night-time movement.

(U) Few of the movements were completely trouble-free. Since the aim of the exercise was to determine navigational accuracy under ideal conditions (ie when ionospherically-limited rather than equipment-limited) the vehicle was air-conditioned to minimise drift in the on-board frequency standard. During the latter part of the exercise the air-conditioning equipment was rendered inoperative because of a partial failure of the vehicle alternator and ancillary equipment; as a consequence, very high temperatures were experienced.

(U) The equipment itself was subject to extreme vibration for thousands of kilometres - particularly over the regularly-traversed stretch between Onslow and the North West Coastal Highway - and on several occasions suffered a temporary failure from this cause. Although it was not possible in such cases to close the traverse, due to loss of computer memory, results could, in general, be salvaged by working forwards and backwards from end-point data. On some occasions when more than one failure occurred it was possible to proceed by re-initialising the base and mobile equipment simultaneously when the next trig. station was reached.

(U) These remote operations were greatly assisted by the excellent HF radio communication maintained between base and vehicle at all times.

(U) Figures 1 and 2 are maps of the region covered. Numbers 1 to 28 have been superimposed to show the positions of the survey marks visited. Table 1 lists these numbers against the official names of the various stations and their latitudes and longitudes. The letters ASO stand for 'Australian Survey Office' and distinguish those stations set up specifically for the trial. The letters ARP stand for 'airport reference peg'. Table 2 is a schedule of the major movements undertaken.

3. ANALYSIS OF RESULTS

Of the seven Omega transmitters in operation at the time of the trial only three produced a satisfactory signal/noise ratio in the Pilbara region, viz Reunion, Japan and Liberia. As expected, Omega Hawaii exhibited a greatly reduced signal level relative to that observed in Adelaide.

(U) Records of the diurnal phase and accompanying signal levels (designated power) of the above four stations on 13.6 kHz taken over a 24 hour period in Onslow are presented in Figures 3-10. The phase angle shown is phase of received signal - phase of local reference oscillator. Thus, an increase of phase angle corresponds with an increase of mean phase velocity between transmitter and receiver. No averaging (designated by "1 - point smoothing" on the photo) has been employed, so that the discrete dots of which the plots are composed represent the phases and amplitudes of the individual transmission bursts of the Omega sequence. The notation 'cal comped' indicates that a correction has been made for temperature-dependent phase error introduced by the receiver. It will be observed that the anomalous behaviour of the Hawaii trace (Figures 9 and 10) circa 0330 (which, incidentally, is rather different in form to that recorded regularly in Adelaide) is not evident to any appreciable extent in the Japan trace (Figures 5 and 6), nor in Japan traces figured subsequently. The diurnal shifts over the period 0830 to 1700, during which most of the movements took place, vary considerably from one Omega station to another. Thus, while Japan shifts phase by only 50°, Reunion and Liberia shift respectively by 130° and 400°. This is the background against which one must view the required degree of correlation of diurnal shift between the base and mobile station if precision of navigation is to be maintained - a de-correlation of 1° produces a radial error of 60 m.

(U) Tables 3 and 4 show the error in incremental radial range from Omega Reunion and Omega Japan as a function of the trig. station visited and the number of the movement (as listed in Table 2). The stations visited are set out from left to right in order of increasing distance from base. Thus No 5 and No 9 stations are respectively 200 and 400 km from Onslow. All readings are based on an averaging period of 16 minutes (96 transmission bursts) and were taken off the on-board processor read-out. Tape print-out produced on return to Defence Research Centre Salisbury permits of a breakdown of these averages into individual bursts and reveals that no significant additional error is introduced when the averaging period is reduced to 5 minutes.

(U) It will be seen from Table 3 that for 95% of the readings based on transmissions from Omega Reunion the radial range error falls within ±200 m, irrespective of distance from Onslow. Results for Omega Japan in Table 4 show rather more scatter, but 85% of the readings fall within the error range of -200/+400 m. In view of the paucity of multiple readings at the more distant sites it is difficult to decide whether there is any real trend towards significant ionospheric de-correlation with increasing distance, over the range covered.

(U) A point of particular interest in Table 4 is that for ranges of up to at least 200 km from base the error values for any given survey mark are fairly consistent although derived from readings taken at different times of day and on different days. This leads one to suspect that a topographical perturbation rather than a propagational effect is responsible for the observed error. Thus at station no. 2, through which every movement passed, and for which the greatest number of readings is available, the error appears as 300 ± 60 m in all cases. Similar instances occur at stations 4 and 17.

(U) In looking for a possible source of phase perturbation at station 2 (which appears to be topographically bland) it was observed that the Perth - Pt Hedland coaxial cable runs a few feet below ground level in the vicinity of the site. With this in mind two offset marks were set up at distances of 50 m and 150 m along the road to Onslow. However, the error values associated with these positions (covered during movements 6 and 7) are similar to those at position 2 so that phase perturbation cannot be a function of position in the immediate vicinity of this particular station.

(U) Position 4 shows considerable perturbation. It may be significant that the survey mark was positioned directly over the cable. It was not possible to carry out offset measurements at this site.

(U) Station 17 was located at a road grid from which a wire fence extended for kilometres in each direction. Here again there is a possibility of signal phase perturbation due to local re-radiation. There is no significant perturbation of the transmission from Omega Reunion at this site. This could well result from the orientation of the re-radiating structure.

(U) It is possible, of course, that the datum point of the various movements ie the Onslow station itself is in a region of phase perturbation since it lies close to a land/sea boundary. However, it is not possible to attribute the error at position 2 solely to this since the mean error of all other stations would then develop a distinctly negative bias, and this seems unreasonable.

(U) The azimuthal bearings of Omega Reunion and Omega Japan from Onslow are respectively $+259^{o}$ and $+14^{o}$ so that the angle of cut of the curves of constant radius is 115^{o}. This produces a 20% geometrical dilution of the positional fix, relative to that for an optimum cut of 90^{o}, for equal radial errors.

(U) Results have not been tabulated for Omega Liberia; its reduced signal strength relative to Reunion coupled with its almost identical bearing makes it less attractive as a primary navigational station. However, an examination of the records reveals that while the scatter is somewhat greater than that for Reunion there do not appear to be any anomalies which can be attributed to ionospheric vagaries. On the other hand it is immediately apparent from an examination of the Hawaii readings that this station cannot be used for navigation in the Pilbara region. Large radial range errors, which appear in random sequence throughout the day, far exceed the standard deviation of any group of readings (already high because of poor signal/noise ratio). One must conclude that transmissions from Hawaii are hopelessly anomalous in North West Australia.

4. IONOSPHERIC DE-CORRELATION AT NIGHT

Movements between trig. stations were scheduled to permit of night-time stop-overs in towns where a mains power supply was available. This facilitated the charging of the lead storage batteries which supplied power to the navigation equipment when mobile, and presented an opportunity to record diurnal phase simultaneously at base and the stop-over position. A selection of the records so obtained appear in Figures 11-73. These comprise the diurnal phases as recorded at base and remote positions, and the differential phase (ie diurnal at mobile - diurnal at base), for transmissions from Omega Reunion, Japan and Liberia on 13.6 kHz. It should be noted that the absolute values of phase angle have no significance in these graphs since the plotter was programmed to equate the most negative value to zero; the scale, of course, is significant.

(U) It will be observed that in certain of the Reunion traces a system of vertical bars appears at intervals on the time axis. These indicate that signal strength has been such as to overload the receiver and render the phase data suspect. However, it is unlikely that any gross error of phase will be present in the particular traces reproduced in this report.

(U) All figures involve an averaging time of 16 minutes ie the average of 96 consecutive Omega bursts in a sliding window, and thus show the angular navigational error which would be introduced by ionospheric de-correlation for this particular averaging period. In view of the excellent correlation which must obtain during the day out to the most distant sites visited - at least for transmissions from Reunion and Japan - the wild excursions of the night-time differentials are at once surprising and disappointing. These excursions are particularly marked in the case of Reunion; figures for Liberia are significantly smaller despite the fact that the Liberian transmitter is located at more than twice the distance of Reunion and the great circle bearings of the two transmitters differ by less than 4°.

(U) Whatever the reason for this, the night-time differentials for each of the Omega transmissions shown is an order greater at each site than would be anticipated from the computed ratio of day/night phase velocity based upon an observation of the diurnal shift at a single location several thousand kilometres from the transmitter. Accordingly, one is led to the conclusion that the spatial integration of progressive phase shift over long paths produces a high degree of smoothing and that records made under such conditions are powerless to predict the magnitude of short-range differentials. This is well illustrated by a comparison of the differential and absolute diurnals for Reunion at Roebourne, Wittenoom and Pt Hedland where the differential shift amounted to more than 1/3 of the absolute variation despite the fact that the radial spacing of these sites from Onslow was 200-400 km while their mean distance from Reunion was over 6000 km.

5. COMPARISON WITH ALTERNATIVE NAVIGATIONAL SYSTEMS

It is of considerable interest to compare the navigational precision of Differential Omega, based upon the Reunion/Japan figures discussed above, with that of alternative systems. Of those which are entirely ground-based only Decca and Loran C need be considered.

(U) The Decca Navigation Company currently operates a marine navigation system in the Dampier/Pt Hedland area. Curves supplied by Decca relating to this installation are reproduced in Reference 2 from which it is seen that the 68% probability contours show a repeatability accuracy of 300 m at a distance of 250 km from the shore in the most favourable direction, under conditions of full daylight. Since Decca would degrade over land it is evident that, for the positions sampled, the absolute accuracy of Differential Omega (topographical anomalies included) is as good or better than the repeatability accuracy of Decca. What the absolute accuracy of Decca may be is not indicated.

(U) From curves presented by Beukers (Reference 3) it would appear that Loran C could be expected to provide an absolute accuracy on land of 250-400 m with 95% probability at distances of 350 km from the transmitters. A considerably less optimistic figure has been suggested in private discussion with another U.S. authority. However this may be, the few Differential Omega fixes taken at this distance from base exhibit errors which do not markedly exceed Beuker's figures. (Nevertheless Loran C excels at night because of its ability to maintain sky wave/ground wave discrimination, while Omega degrades substantially, as shown in Section 4).

(U) Satellite navigation is currently based on the Transit system. The order of accuracy for ship-board receivers is generally stated to be 0.05 to 0.10 nautical miles plus 0.20 nautical miles per knot of ground speed error. This compares unfavorably with daylight Differential Omega, even when allowance is made for the fact that speed and heading inputs must be supplied to the Omega equipment when phase data are time - averaged and read-out of instantaneous position is required. More importantly, however, satellite passes occur only at intervals of 30 to 110 minutes, depending upon latitude, so that alternative means of navigation must be employed between updates (Omega is often used for this purpose).

(U) The Navstar Global Positioning System holds out the greatest promise of navigational precision - say 15 m in plan position and altitude. Trials carried out to date with the satellite system about one-third complete suggest that this could be possible, but the system may not be operational until the late eighties. For security reasons this order of accuracy will not be made available for civilian use (Reference 4). It is presently proposed that receivers released to the public should operate with a 'coarse signal' accuracy of 500 m on a 95% probability basis, but this will be the subject of annual review.

(U) Each of the navigational systems considered above is externally-referenced and could become a war-time casualty. Apart from the question of satellite vulnerability, it should be noted that Navstar requires five ground stations for monitoring and control and that the loss of any one of these would lead to a degradation of overall performance.

6. PERTH-ADELAIDE DIFFERENTIALS

Although not envisaged in the original plan, the opportunity was taken during the post-trial return of equipment to Defence Research Centre Salisbury to record a set of diurnals simultaneously in Perth and Adelaide on three Omega frequencies, viz 13.6, 11.3 and 10.2 kHz. A selection of diurnals, diurnal differences and signal strength plots is presented in Figures 74-117. Local time in all cases refers to Perth time, ie UTC + 8 hours.

(U) Turning to the 13.6 kHz Reunion traces shown in Figures 74-76, we see that a solar flare discontinuity is apparent at 1530 hours. The amplitude of this transient amounts to about 75° in Adelaide while the differential amplitude is only about 15°. Daylight correlation between Perth and Adelaide is good; over the interval 0800 to 1600 hours the maximum variation of the differential (transient excepted) is $\pm 12^{\circ}$ (ie, in terms of equivalent distance, ±750 m).

At night the discrepancy increases to about 150^{o} which is little more than the de-correlation found to arise between Onslow and Roebourne where the relevant displacement is 230 km as compared with 2200 km for Adelaide and Perth.

(U) Figures 77-81 cover diurnal phase and signal strength plots for Japan on 13.6 kHz over the same period as the Reunion traces considered above. The solar-induced discontinuity has again been reduced in the differential plot to about 20% of its absolute value. A high degree of daylight correlation is apparent, the differential variation amounting to only $\pm 10^{o}$ between 0800 and 1500 hours. The two diurnals are of similar shape but displaced in time so that the difference plot approximates the first time derivative of the diurnals. In this connection it should be noted that Omega Japan is located close to the mean longitude of Adelaide and Perth. Apart from the sunrise and sunset perturbations, the variation of phase differential is less than $\pm 25^{o}$ over the 24 hour period. When interpreting signal strength traces it should be borne in mind that recordings made at different sites have no common datum, while recordings made at a given site on a given day correctly display the relative amplitudes of the various Omega transmissions.

(U) Traces of the Liberian signal are shown in Figures 82-84. In spite of the superficial resemblance of the absolute diurnals the difference plot displays no long-term correlation. The discrepancy of phase between the end points results from the necessity, for technical reasons, of terminating the plot at 0400 hours.

(U) Figures 85-117 cover the frequencies 11.3 and 10.2 kHz. It is seen that the Reunion traces (Figures 85-92) exhibit about the same degree of correlation as for 13.6 kHz. Liberia (Figures 93-102) shows a surprisingly small variation in the 11.3 kHz difference plot of $\pm 20^{o}$ at all times except sunrise, but in the absence of confirmatory data its consistency cannot be assumed. Its differential behaviour on 10.2 kHz is less impressive.

(U) More interestingly, two sets of diurnals recorded from Japan on 11.3 kHz (Figures 103-112) show a marked difference, in respect of the Perth traces, from those recorded on 13.6 kHz, although the Adelaide traces show no significant differences. The Perth plots are, however, internally inconsistent, the trace of 28/29 September showing signs of anomalous behaviour circa 0400 hours. This is not apparent in the trace of 26/27 September, where the signal level is seen to be higher. The anomalous behaviour at Perth is repeated in a 10.2 kHz trace taken on 30 September/1 October (Figures 113-117), where it has been sufficiently severe to cause a cycle slip in the phase record. The horizontal portions of the trace following the cycle slip result from the operation of the plotter which is programmed to clamp the phase at its last value when the signal level falls below a preset value.

7. CONCLUSIONS

It has been found possible to carry out accurate land navigation during daylight hours in North West Australia by employing the Differential Omega system of navigation in a range/range mode which utilizes transmissions from Omega Reunion and Omega Japan.

(U) Navigational errors, most conveniently described in terms of the errors of radial range from the transmitting stations, were less than ±200 m for 95 % of the observations based on Reunion and lay between -200 and +400 m for 85% of the observations based on Japan, at ranges of up to 400 km from base. These results include perturbations associated with topographical features; repeatability was considerably better. A statistical break down, however, is not justified since some of the sites were visited only once or twice.

(U) By comparison, night-time accuracy was very poor, ionospheric de-correlation being much more severe than would be anticipated from observation of diurnal phase at a single location several thousand kilometres from the transmitter, and linearly interpolated. Thus Omega Reunion exhibited peak values of phase de-correlation amounting to 3% or 4% of distance at a range of 100 km and about 2% at 400 km.

(U) The Perth/Adelaide diurnals for Reunion and Japan on 13.6 kHz exhibit a high degree of daylight correlation with radial range discrepancies of 750 m or less. The smooth nature and probable repeatability of the differential diurnals suggests that the use of differential predictions would permit of land navigation between Adelaide and Perth with a daylight accuracy of several hundred metres (topographical perturbations excepted), with ionospheric corrections being transmitted from one end only.

(U) It should be borne in mind that the navigational results presented above exclude 'clock' error ie error deriving from offset between the frequency standard carried on the vehicle and that maintained at base. The problem may be avoided by operation in a hyperbolic rather than a range/range mode, but this requires that three Omega transmissions be monitored rather than two. This should pose no problem when Omega Australia is commissioned, hopefully within the current fiscal year.

8. ACKNOWLEDGEMENTS

Thanks are due to Mr L. Lavers, Senior Surveyor, ASO, Adelaide, to Mr R. Comber, Chief Surveyor, ASO, Perth, and to Mr D. McKellar, Senior Surveyor for the North West for advice and assistance freely offered. The efficient execution of the trial was made possible through the efforts of Mr P. Hunt and the members of his field team who travelled 14,000 km under arduous conditions to set up and calibrate new roadside trig. stations, and to update access data for existing marks.

(U) The author also wishes to acknowledge the assistance rendered by Mr D. McCutcheon, Shire Clerk of the West Pilbara Shire Council and by members of his staff during the commissioning and de-commissioning of the base station in Onslow.

(U) Finally, the author desires to acknowledge his indebtedness to the members of the navigation team - Allan Padgham, John Bower and Wayne Dangerfield - who carried out their duties cheerfully and efficiently, and displayed considerable resource in the face of unforeseen difficulties.

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3	Beukers, J.M.	"Radio Navigation in North America - the next 25 years". 30th Annual Meeting of The Institution of Navigation, San Diego, Cal., June 1974
4		"Aviation Week and Space Technology". p. 66, April 20, 1981

TABLE 1. TRIG STATIONS AND LOCATIONS

MAP NO.	NAME OF STATION	LATITUDE (S) LONGITUDE (E)	MAP NO.	NAME OF STATION	LATITUDE (S) LONGITUDE (E)
1	R 299 (ONSLOW)	21 38 08.9 115 06 26.1	15	ASO 1010	22 37 40.8 117 39 07.9
2	ASO 1001	22 09 03.2 115 32 25.1	16	NM/F/631	22 59 32.6 117 03 03.2
3	ASO 1002	21 35 52.9 115 56 22.3	17	ASO 1012	22 39 53.0 116 13 10.8
4	ASO 1003	21 06 41.6 116 14 06.4	18	ASO 1013	22 45 37.6 115 08 05.5
5	ASO 1004	20 47 50.3 116 46 40.4	19	KAP 14	23 09 02.1 114 30 18.8
6	WELCOME	20 46 23.8 117 08 23.1	20	5CY	23 26 01.8 114 16 05.0
7	ASO 1005	20 54 17.0 117 21 40.9	21	NM/F/579 (MANBERRY)	23 57 41.0 114 08 59.4
8	ASO 1006	20 48 23.0 118 08 07.0	22	PSM 49	24 53 14.7 113 39 43.2
9	HEDLAND ARP	20 22 45.1 118 37 30.6	23	KAP 16	23 19 54.2 113 49 34.5
10	ASO 1007	21 34 25.6 117 12 54.5	24	ASO 1018	22 40 29.0 114 19 00.1
11	ASO 1008	21 49 48.8 117 55 21.0	25	NM/F/523 (MIDWAY)	22 31 37.1 114 00 42.6
12	WITTENOOM ARP	22 13 27.7 118 20 54.5	26	FS4 (LEARMONTH)	22 15 04.9 114 04 37.2
13	ASO 1016	22 15 14.9 117 41 22.1	27	ASO 1019	22 07 43.5 114 04 53.1
14	ASO 1009	22 23 55.8 117 52 56.8	28	ASO 1000	21 57 23.8 114 08 09.1

TABLE 2. SCHEDULE OF MOVEMENTS

(1) Onslow/Pt Hedland/Roebourne/Onslow 29/31 July 1980

29 July:	1 to Pt Hedland (no survey stations visited en route) Overnight recording in Pt Hedland
30 July:	9,8,7,6. Overnight recording in Roebourne
31 July:	6,5,4,3,2,1.

(2) Onslow/Roebourne/Wittenoom/Tom Price/Onslow 3/6 August 1980

3 August:	1,2,3,4,5,6. Overnight recording in Roebourne
4 August:	7,10,11,12. Overnight recording in Wittenoom
5 August:	14,15. Overnight recording in Tom Price
6 August:	15,16,17,2,1.

(3) Onslow/Carnarvon/Barradale/Onslow 10/12 August 1980

10 August:	1 to Carnarvon (no survey stations visited en route) Overnight recording in Carnarvon
11 August:	22,21,20,19. Overnight recording in Barradale
12 August:	18,2,1.

(4) Onslow/Exmouth/Barradale/Onslow 16/19 August 1980

16 August:	1,24,25,26,28 Overnight recording at Exmouth
17 August:	28,27,26,25,23,27,28. Overnight recording at Exmouth
18 August:	28,27,26,25,24,19. Overnight recording at Barradale
19 August:	18,2,1.

TABLE 2(CONTD.).

(5) Onslow/Roebourne/Wittenoom/Tom Price/Onslow 22/25 August 1980

22 August:	1,2,3,4,5,6. Overnight recording in Roebourne
23 August:	7,10,13. Overnight recording in Wittenoom
24 August:	12,14,15. Overnight recording in Tom Price
25 August:	15,16,17,2,1.

(6) Onslow/Roebourne/Onslow 29/30 August 1980

29 August:	1,2,3,4,5,7. Overnight recording in Roebourne
30 August:	7,5,4,3,2,2A,2B,1.

(7) Onslow/2/Onslow 31 August 1980

1,2A,2,2B,1.

TABLE 3. INCREMENTAL RADIAL RANGE ERROR (OMEGA REUNION)

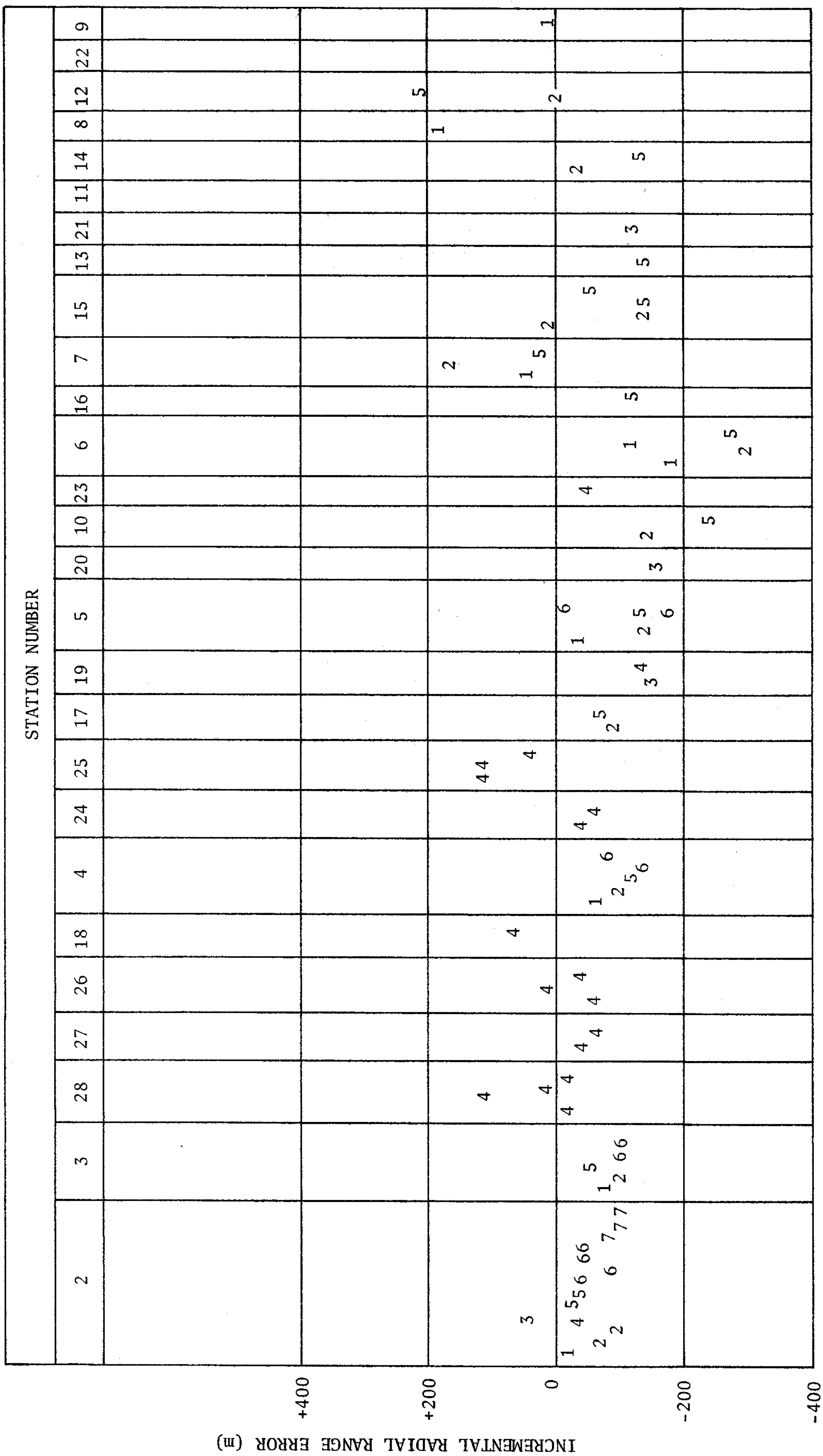
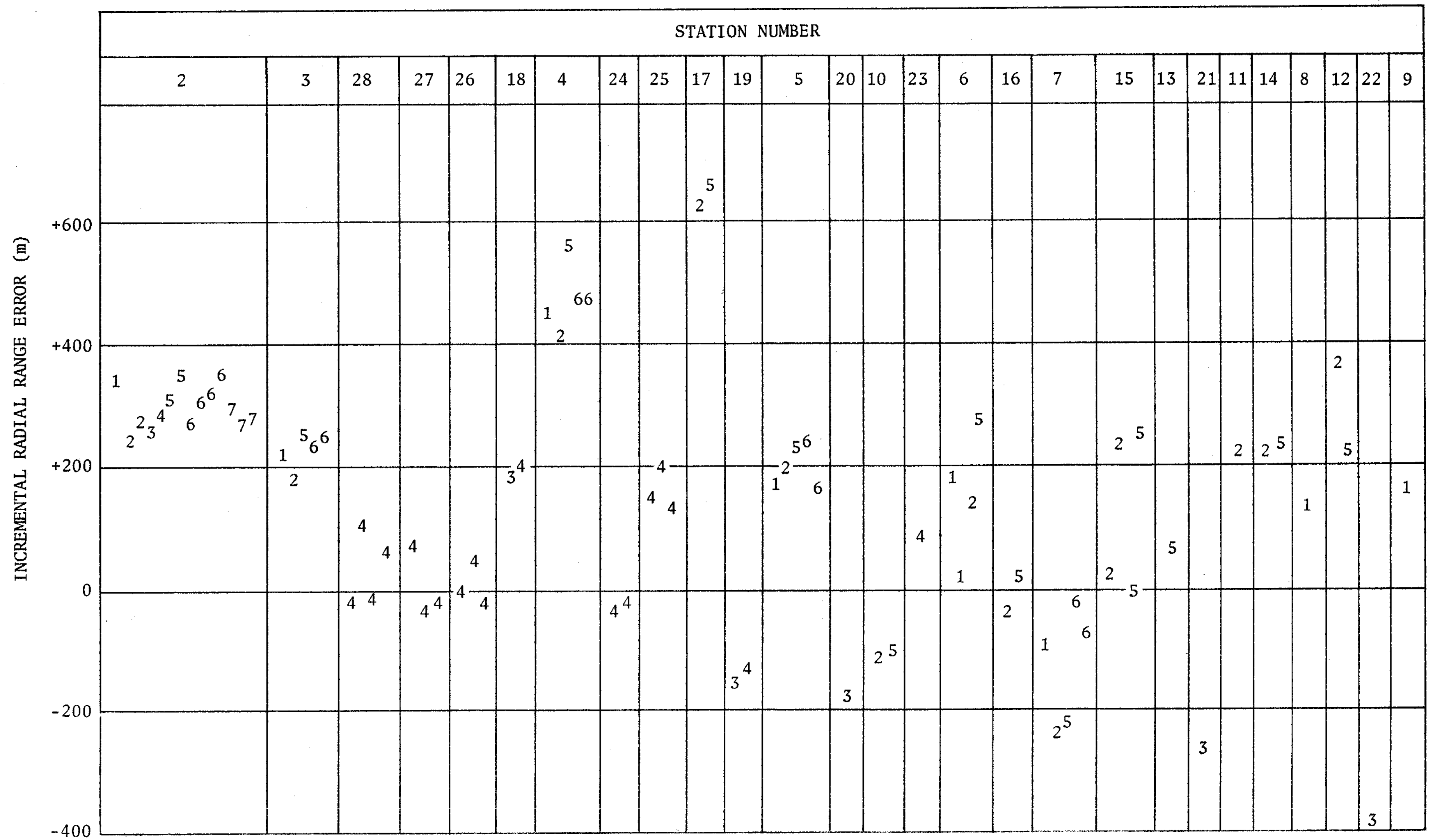


TABLE 4. INCREMENTAL RADIAL RANGE ERROR (OMEGA JAPAN)



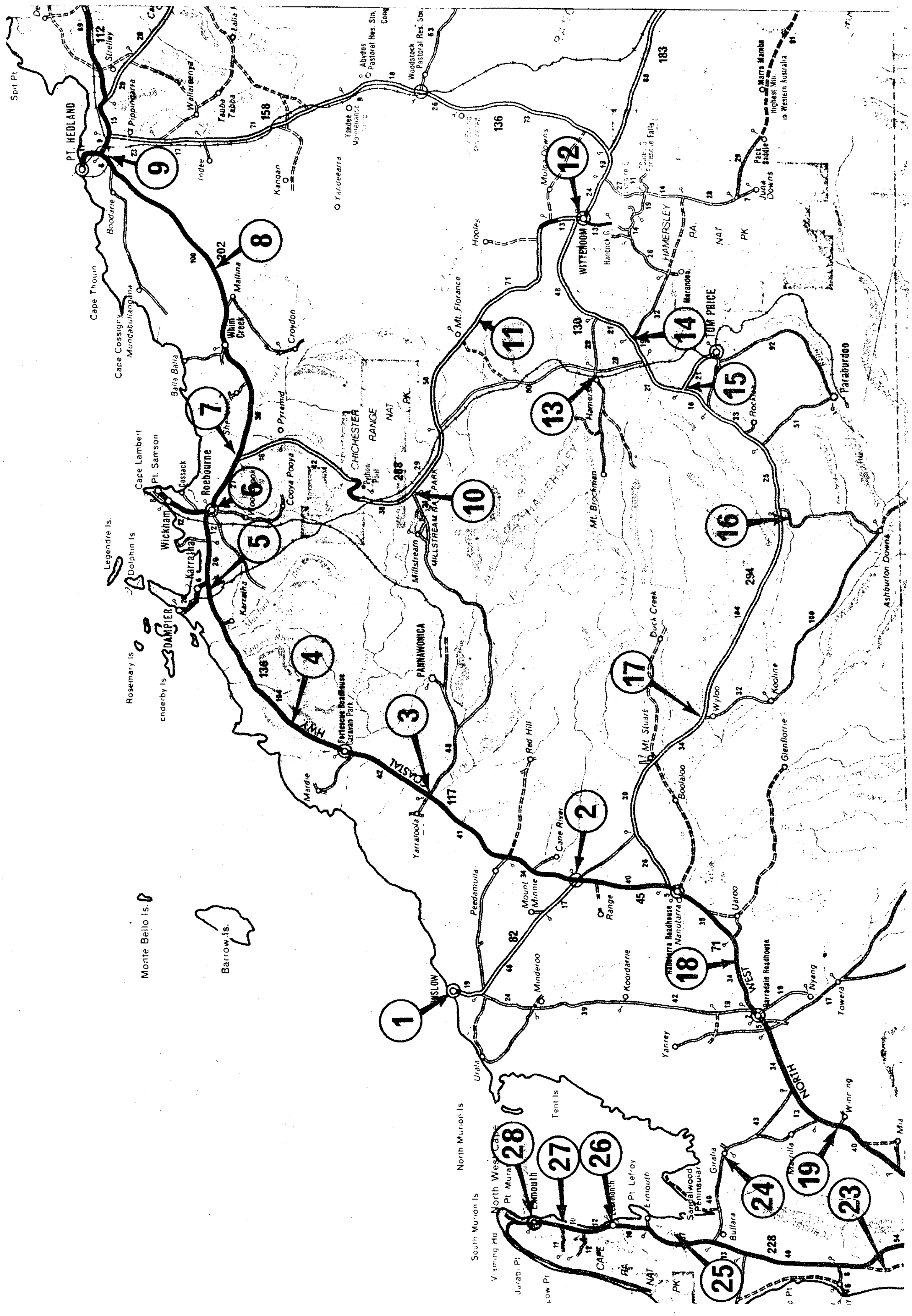


Figure 1. Map of north-eastern region

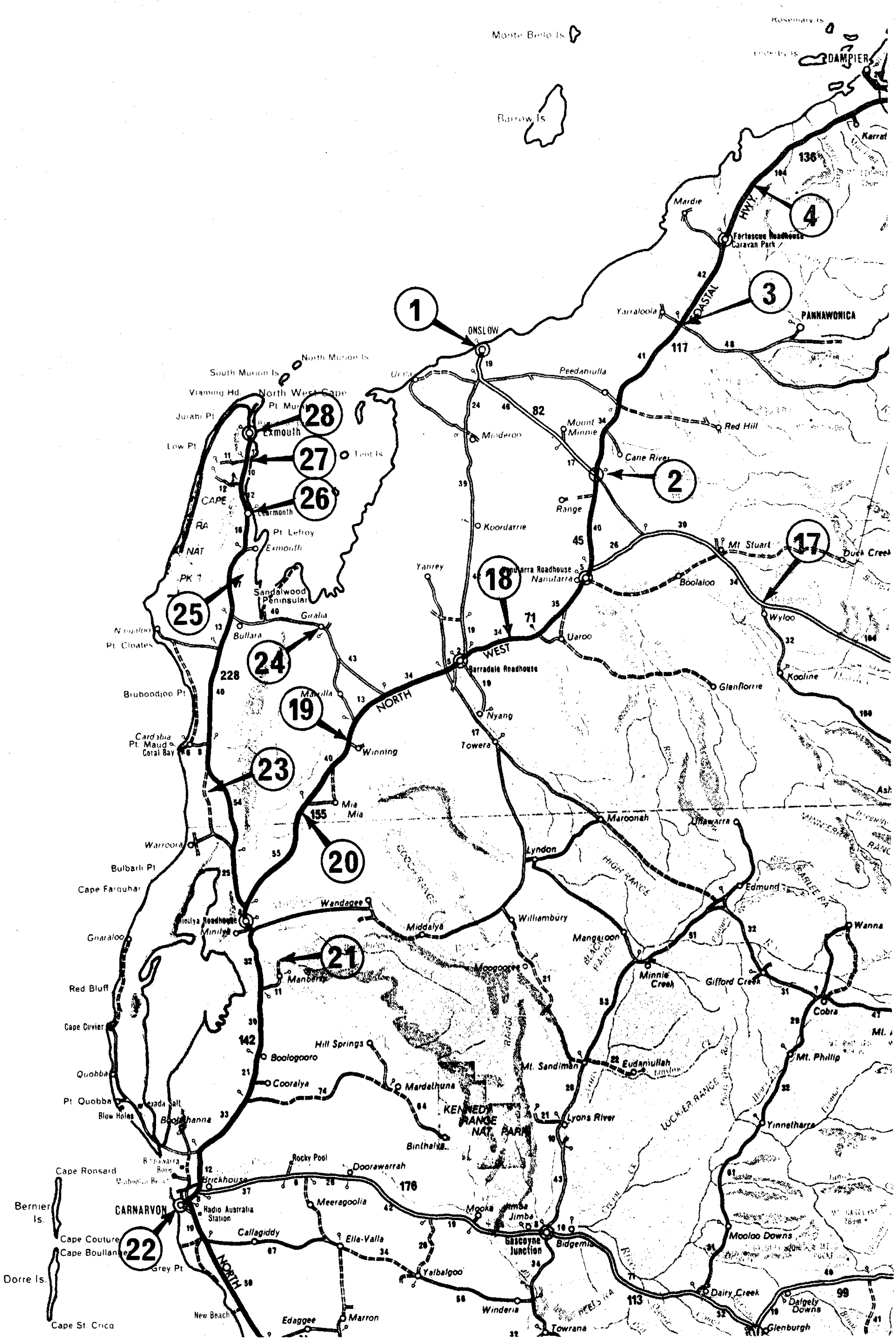


Figure 2. Map of south-western region

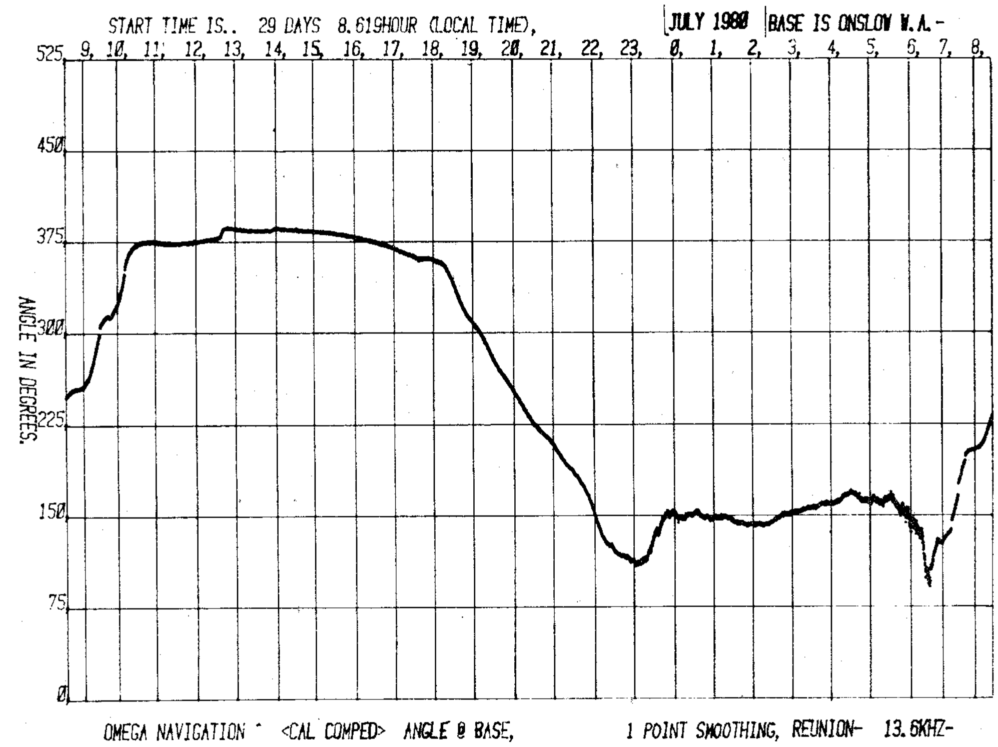


Figure 3. Diurnal phase of Reunion in Onslow on 13.6 kHz 29/30 July

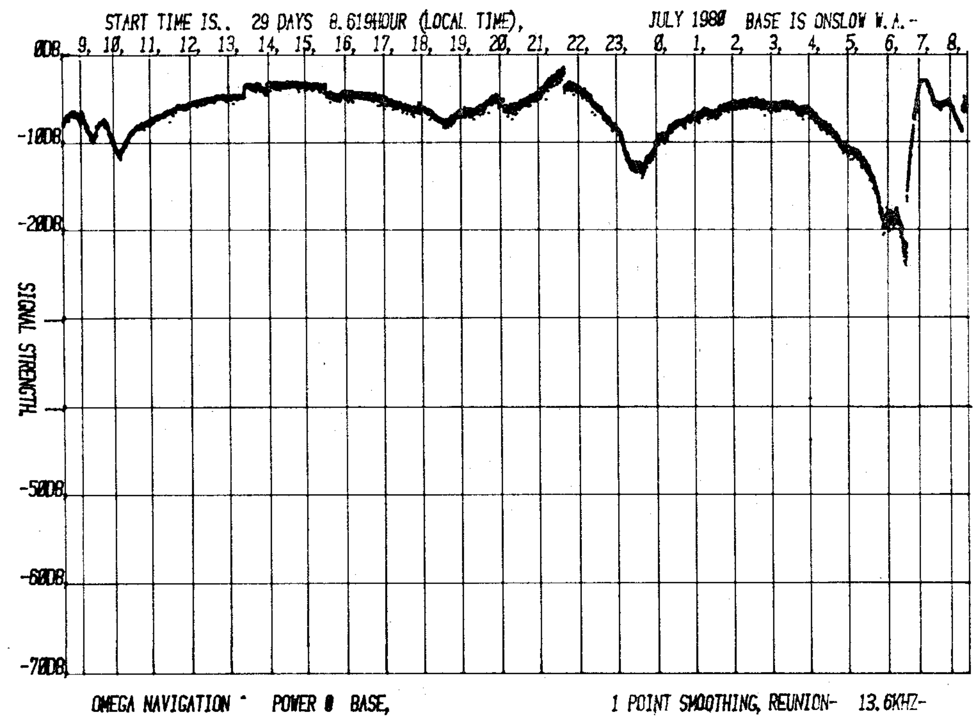


Figure 4. Signal level of Reunion in Onslow on 13.6 kHz 29/30 July

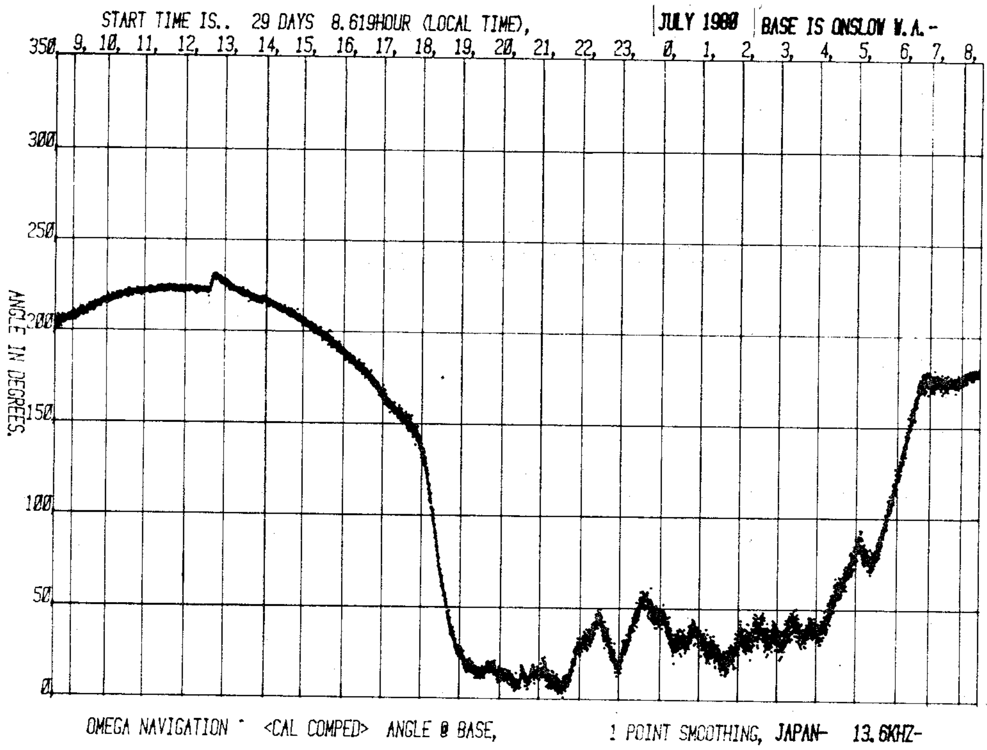


Figure 5. Diurnal phase of Japan in Onslow on 13.6 kHz 29/30 July

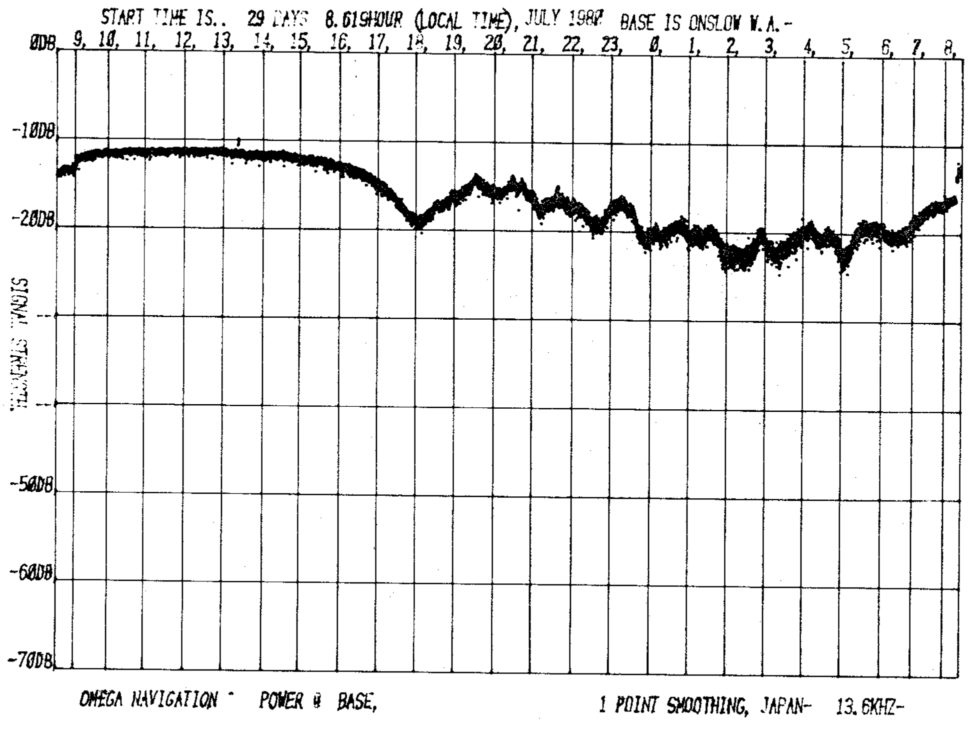


Figure 6. Signal level of Japan in Onslow on 13.6 kHz 29/30 July

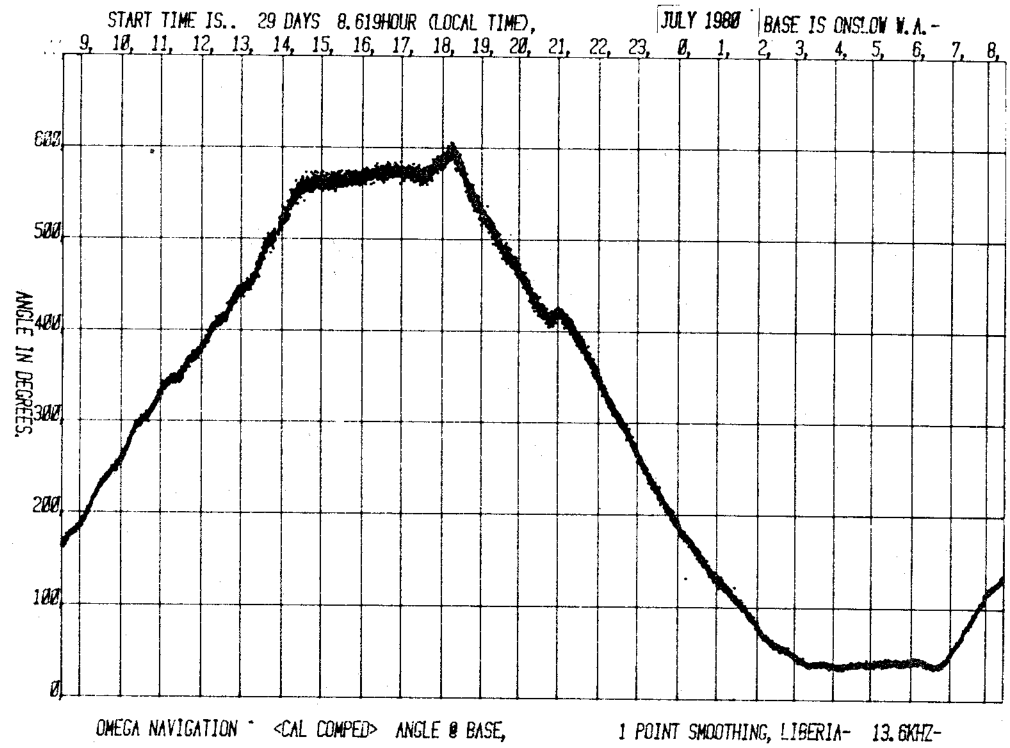


Figure 7. Diurnal phase of Liberia in Onslow on 13.6 kHz 29/30 July

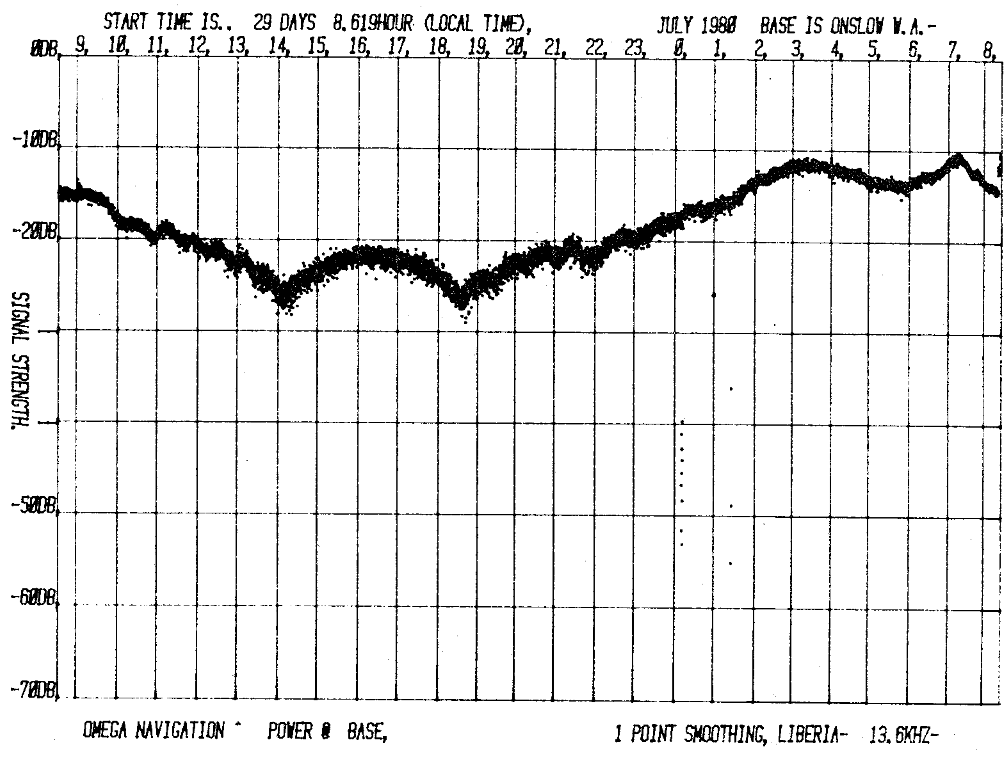


Figure 8. Signal level of Liberia in Onslow on 13.6 kHz 29/30 July

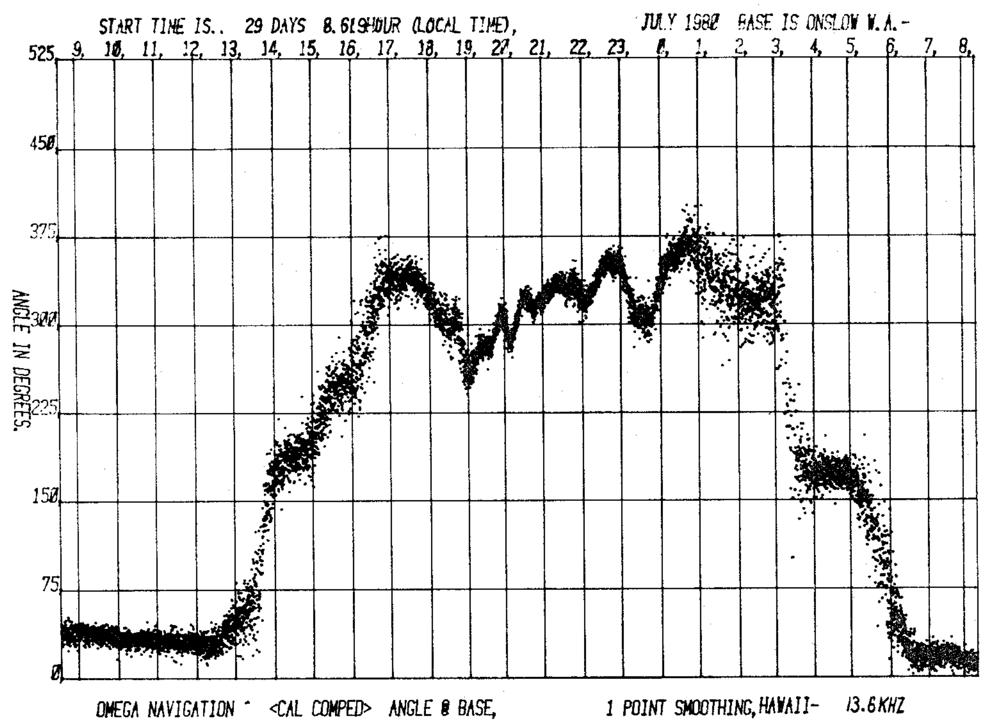


Figure 9. Diurnal phase of Hawaii in Onslow on 13.6 kHz 29/30 July

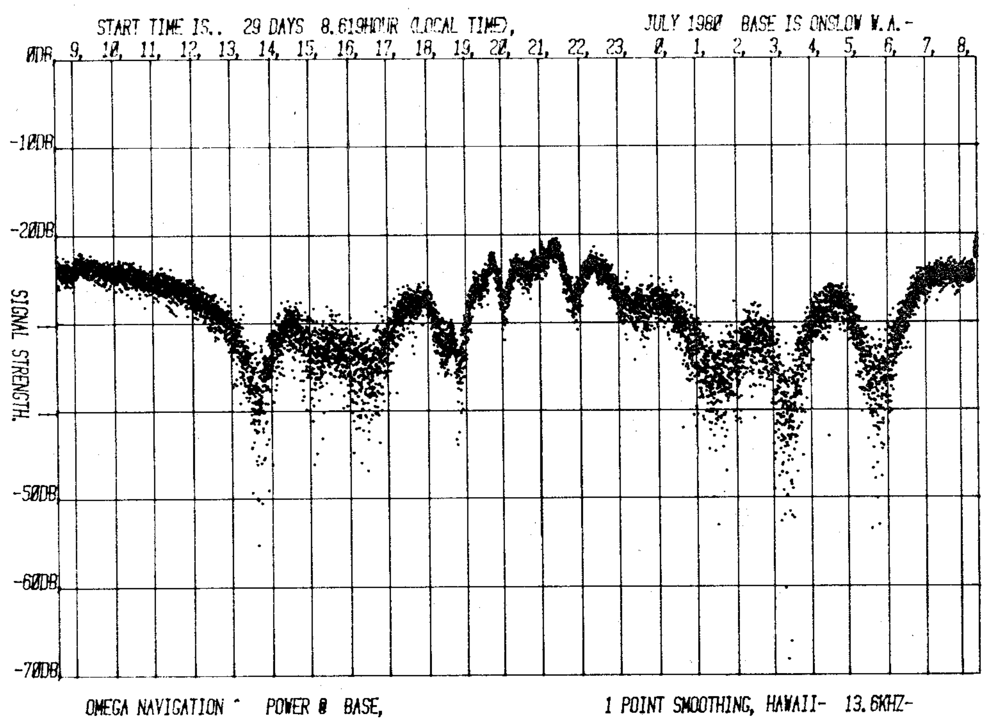


Figure 10. Signal level of Hawaii in Onslow on 13.6 kHz 29/30 July

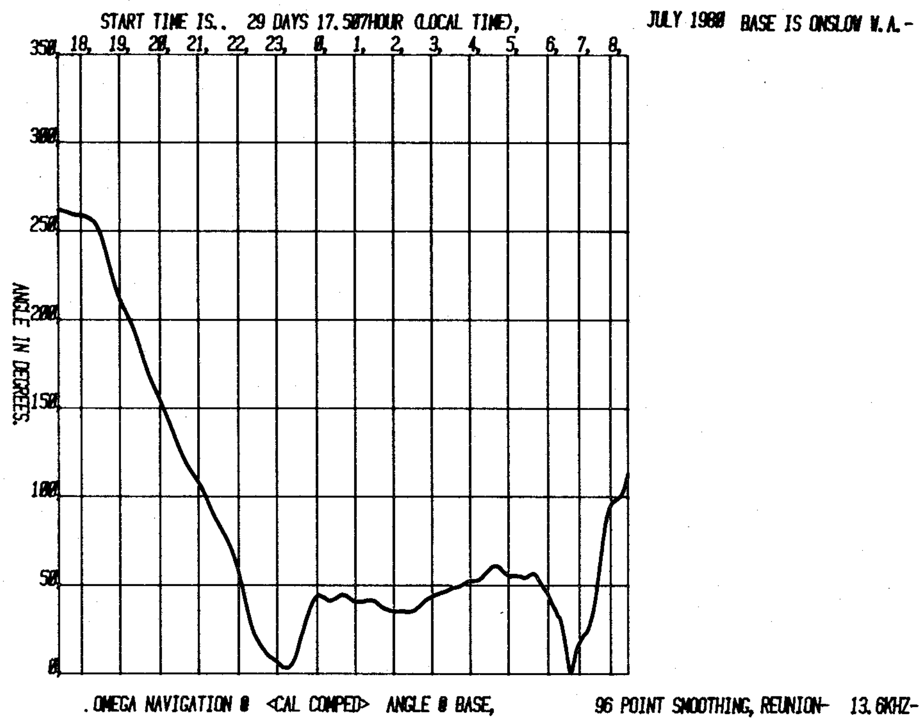


Figure 11. Overnight phase of Reunion in Onslow on 13.6 kHz 29/30 July

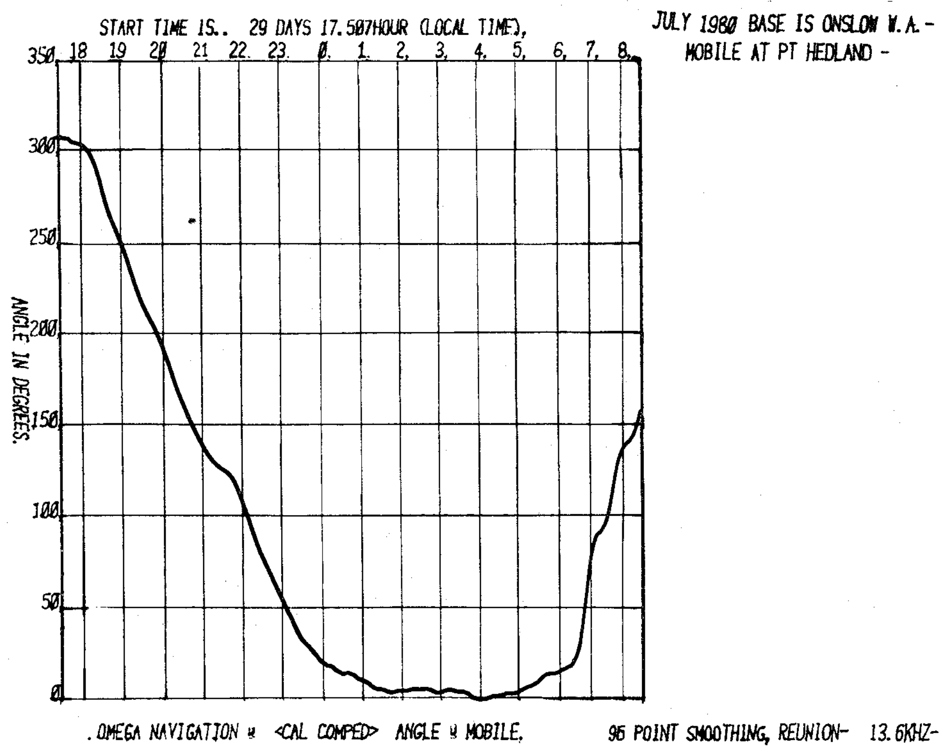


Figure 12. Overnight phase of Reunion in Pt Hedland on 13.6 kHz 29/30 July

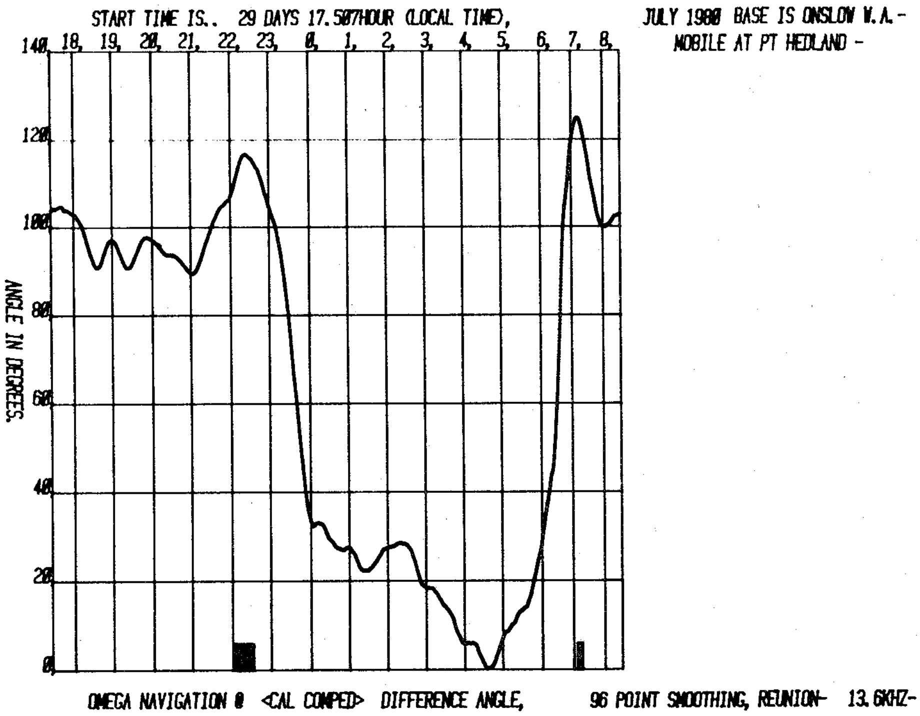


Figure 13. Angular difference (12)-(11)

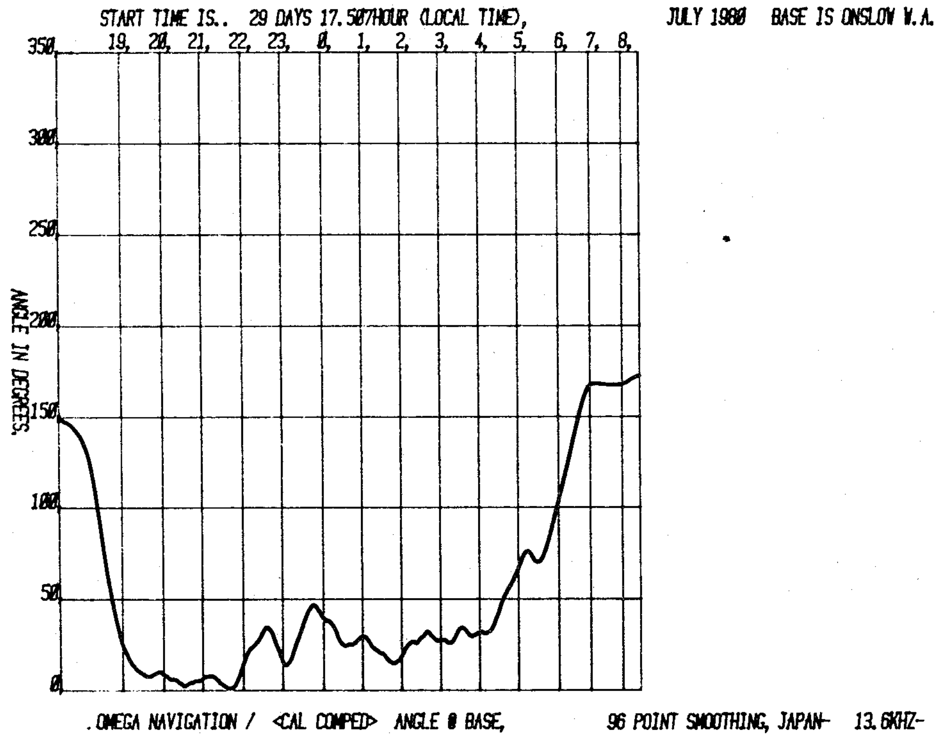


Figure 14. Overnight phase of Japan in Onslow on 13.6 kHz 29/30 July

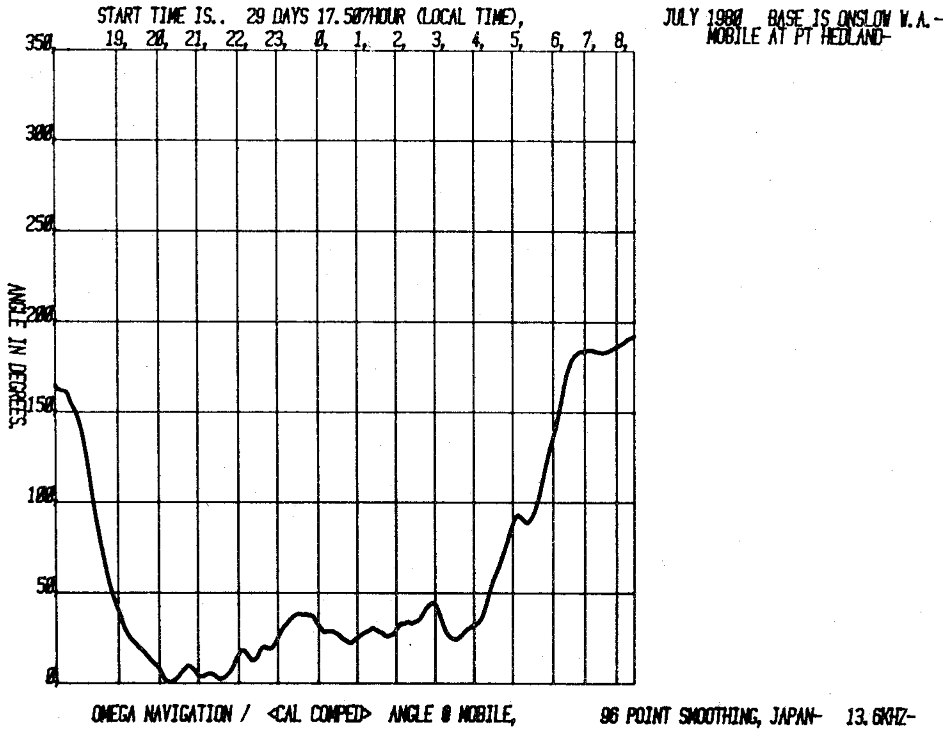


Figure 15. Overnight phase of Japan in Pt Hedland on 13.6 kHz 29/30 July

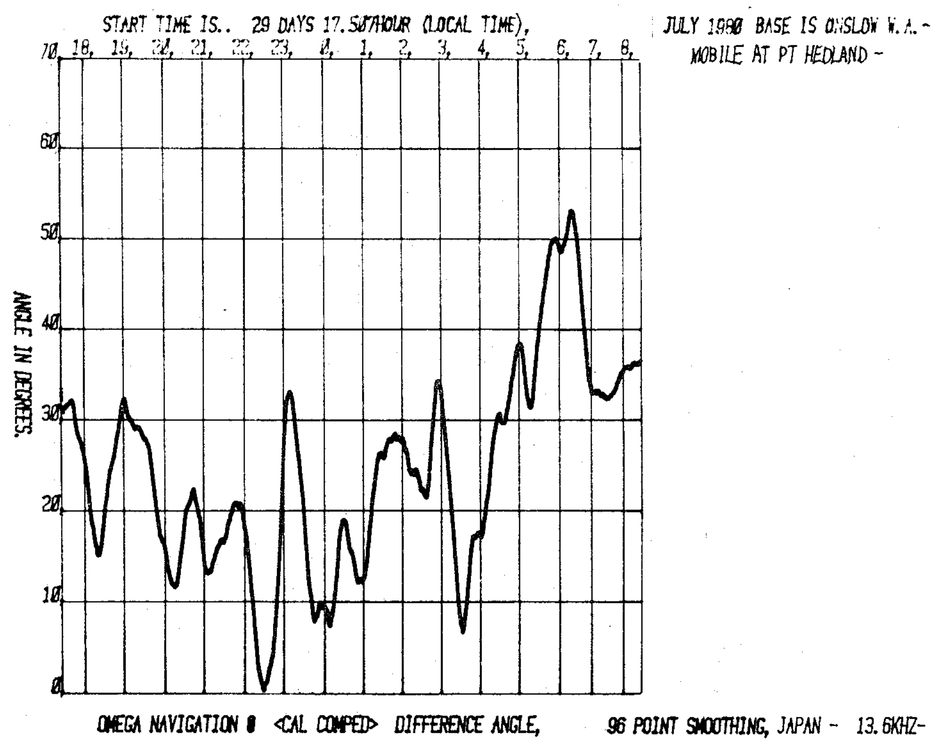


Figure 16. Angular difference (15)-(14)

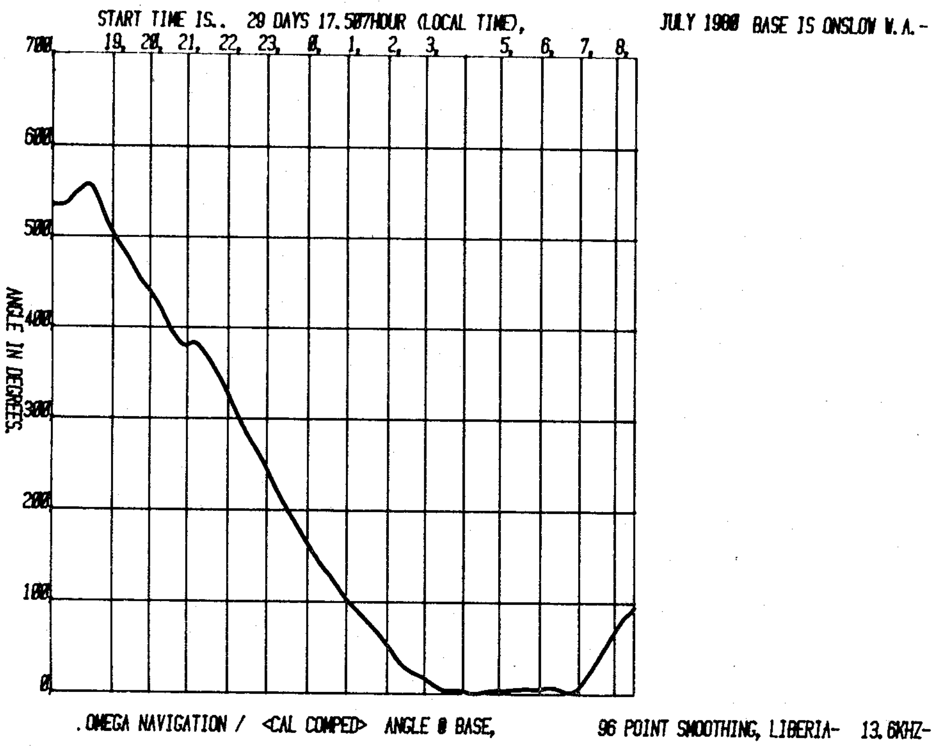


Figure 17. Overnight phase of Liberia in Onslow on 13.6 kHz 29/30 July

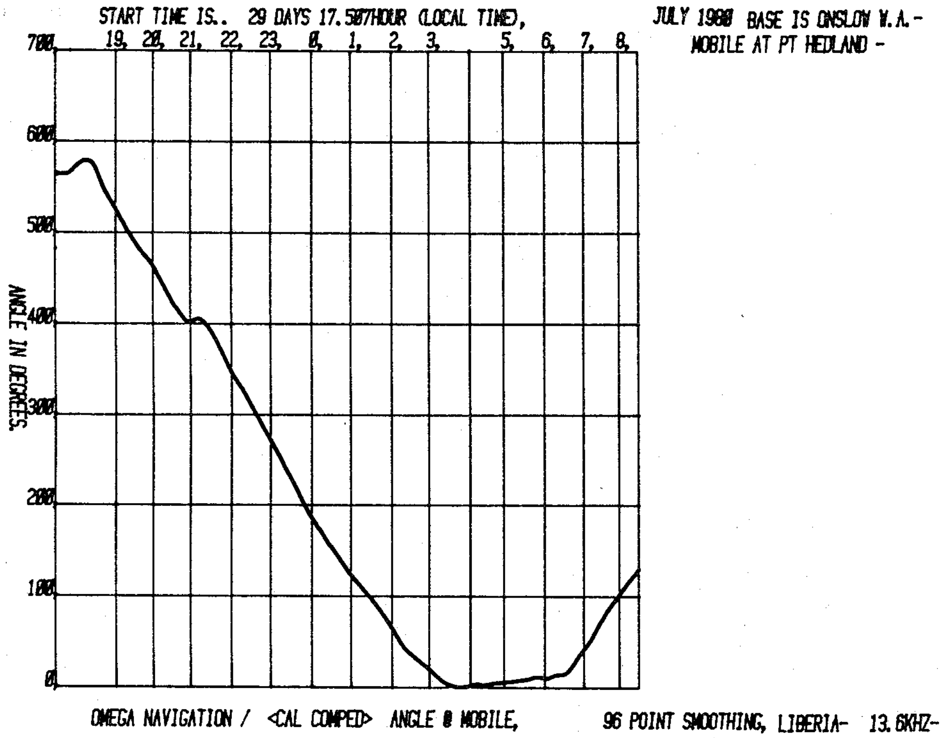


Figure 18. Overnight phase of Liberia in Pt Hedland on 13.6 kHz 29/30 July

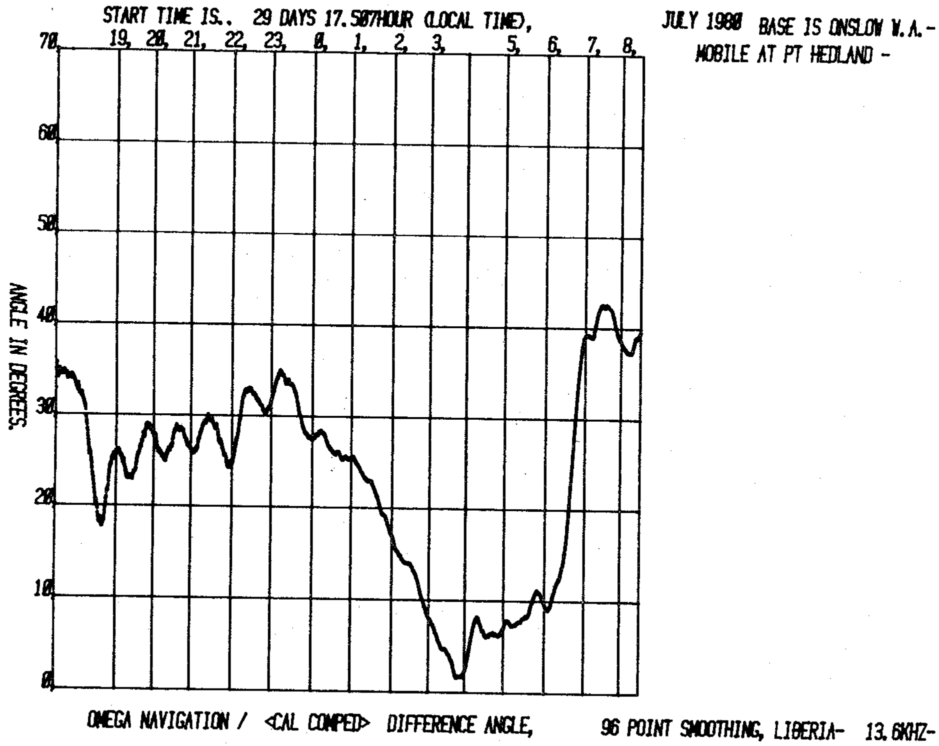


Figure 19. Angular difference (18)-(17)

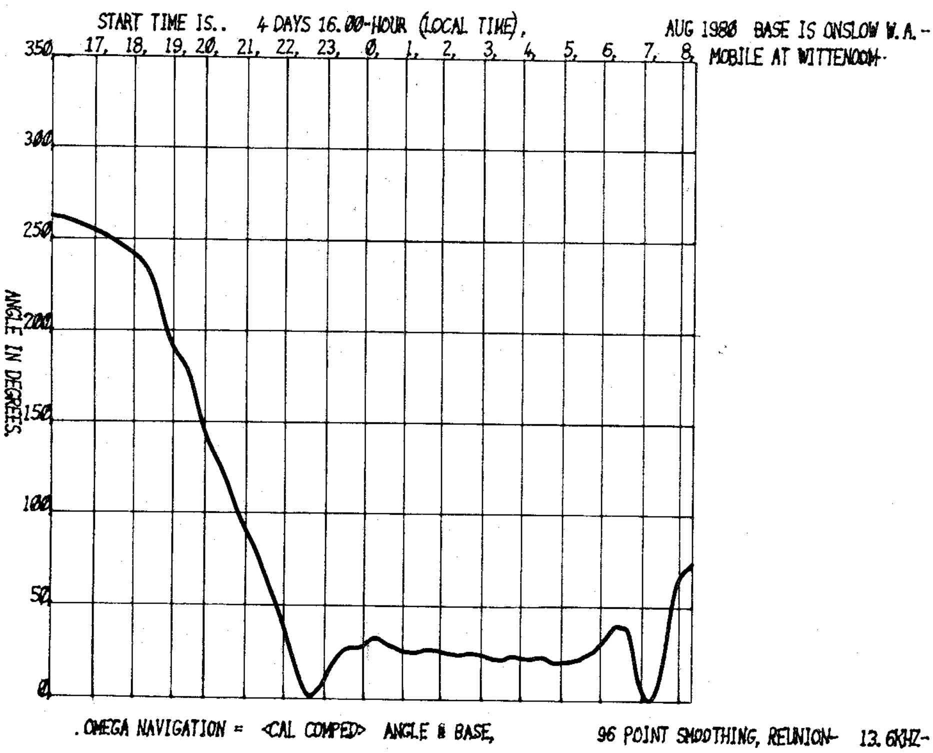


Figure 20. Overnight phase of Reunion in Onslow on 13.6 kHz 4/5 August

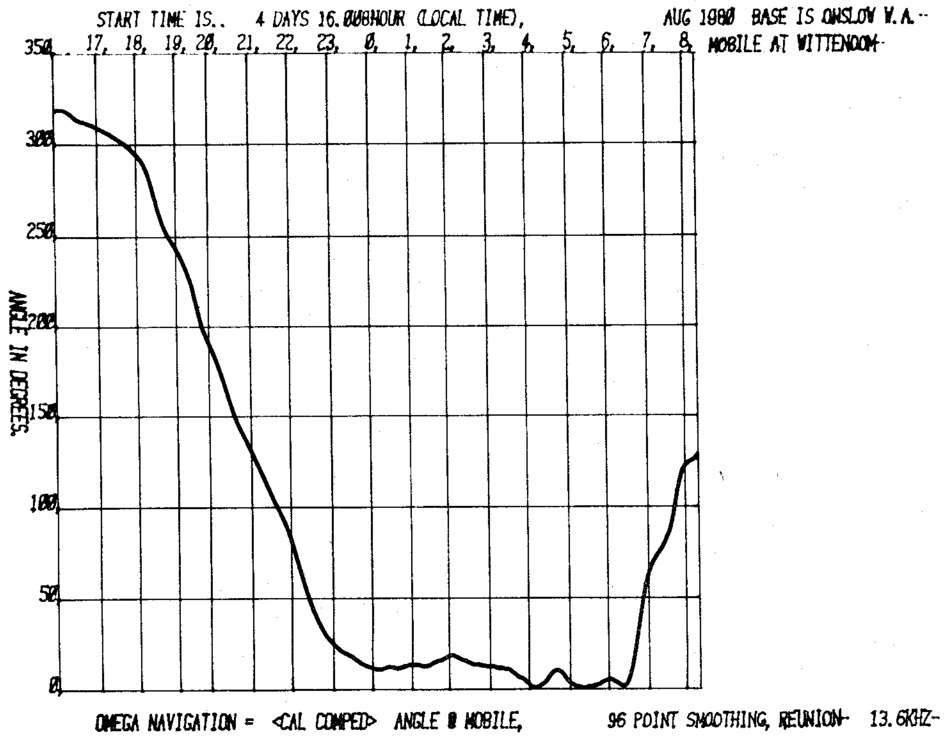


Figure 21. Overnight phase of Reunion in Wittenoom on 13.6 kHz 4/5 August

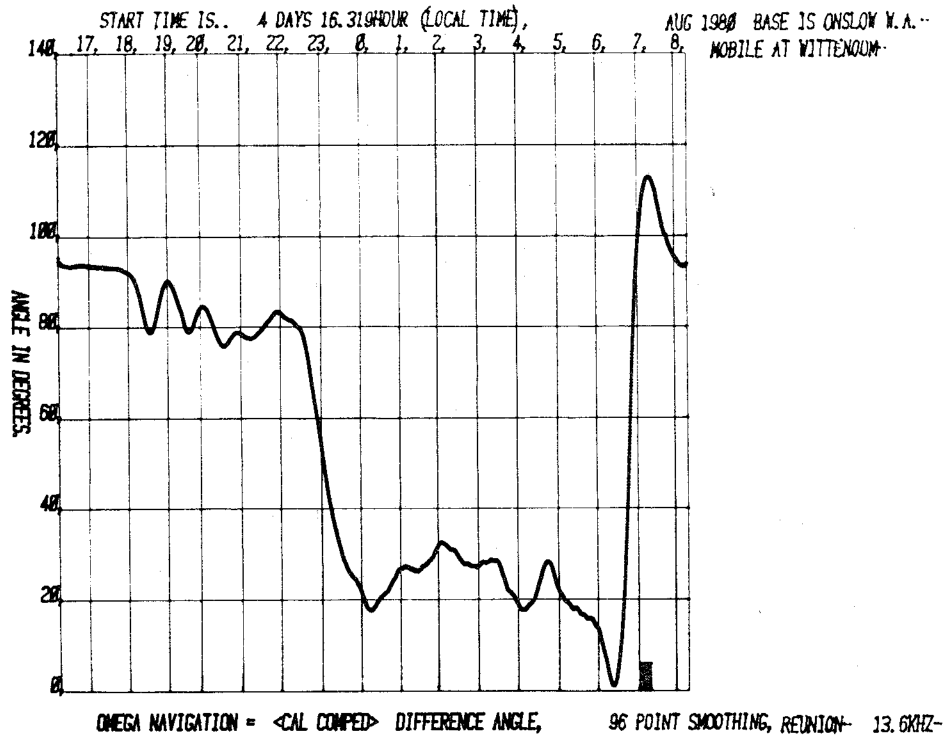


Figure 22. Angular difference (21)-(20)

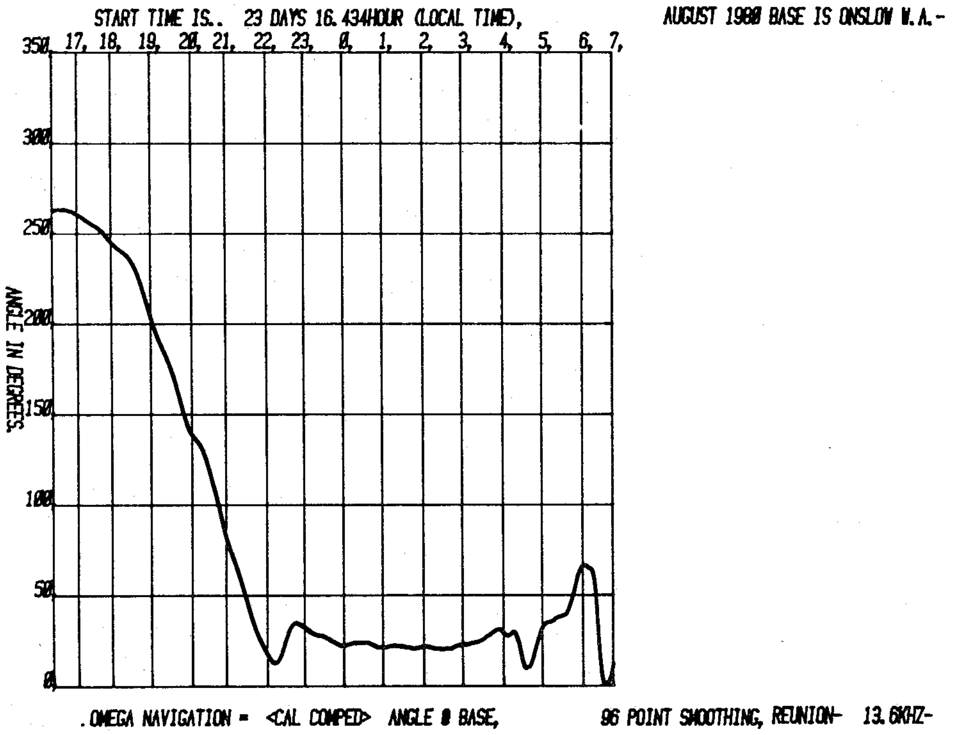


Figure 23. Overnight phase of Reunion in Onslow on 13.6 kHz 23/24 August

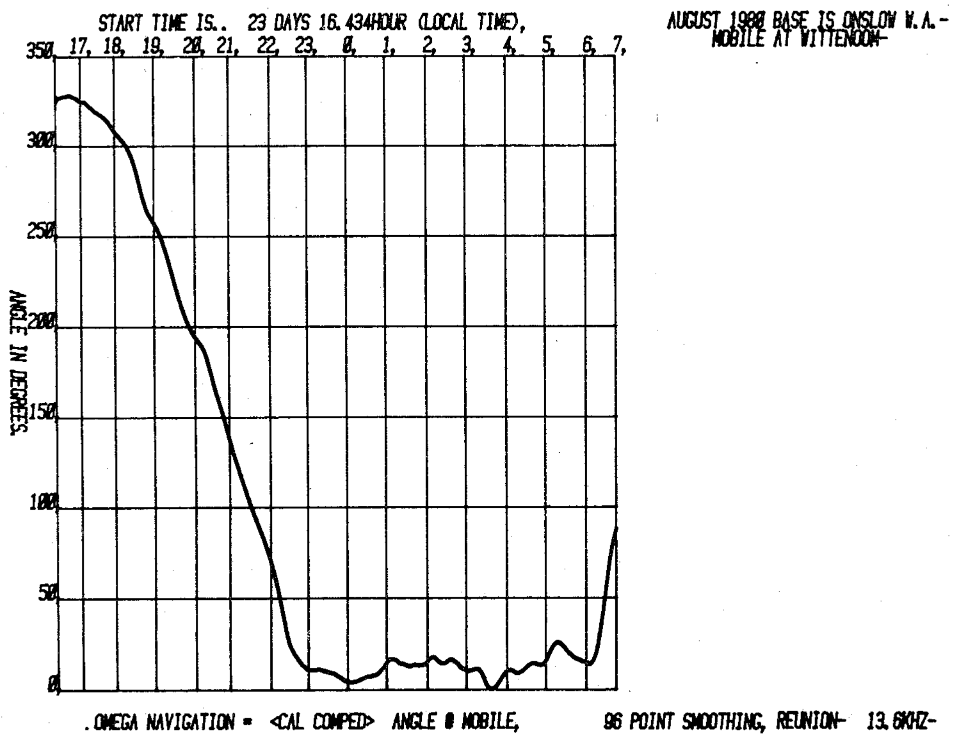


Figure 24. Overnight phase of Reunion in Wittenoom on 13.6 kHz 23/24 August

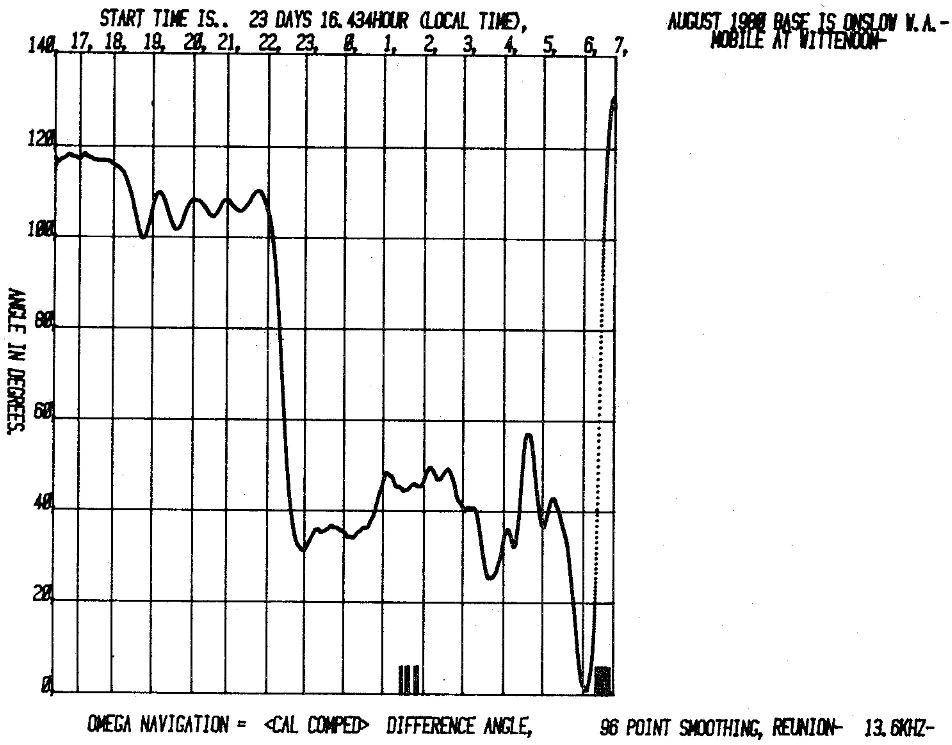


Figure 25. Angular difference (24)-(23)

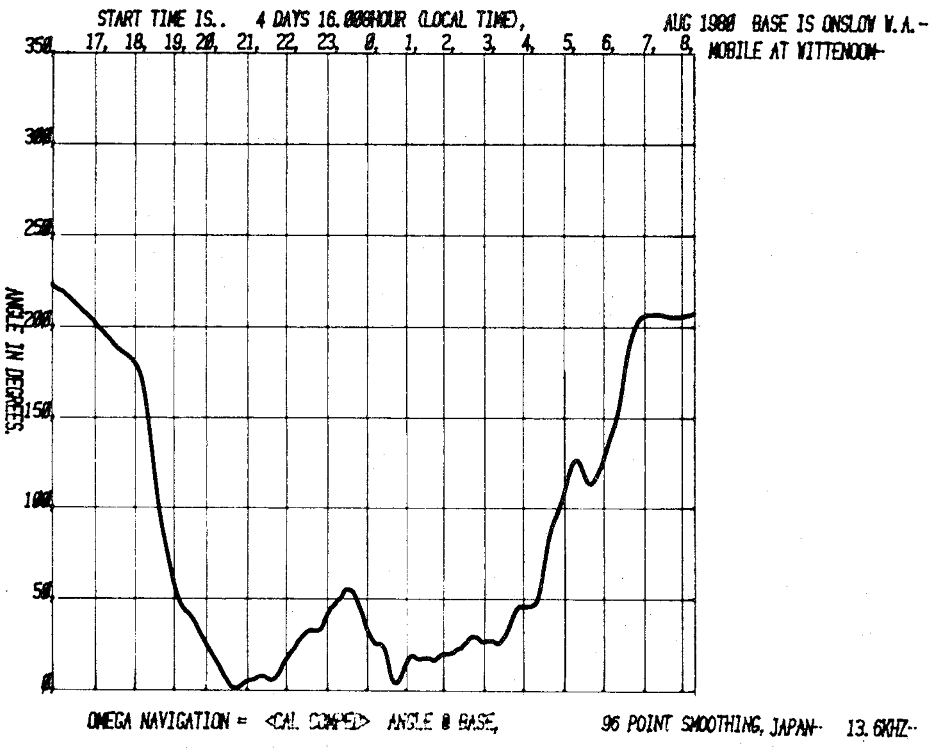


Figure 26. Overnight phase of Japan in Onslow on 13.6 kHz 4/5 August

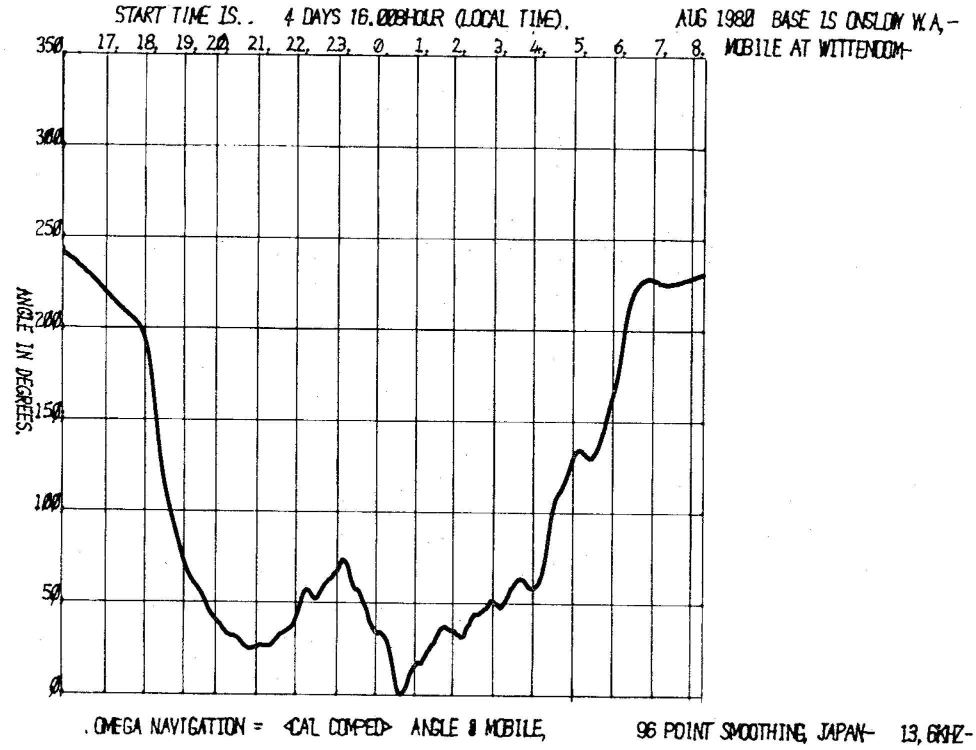


Figure 27. Overnight phase of Japan in Wittenoom on 13.6 kHz 4/5 August

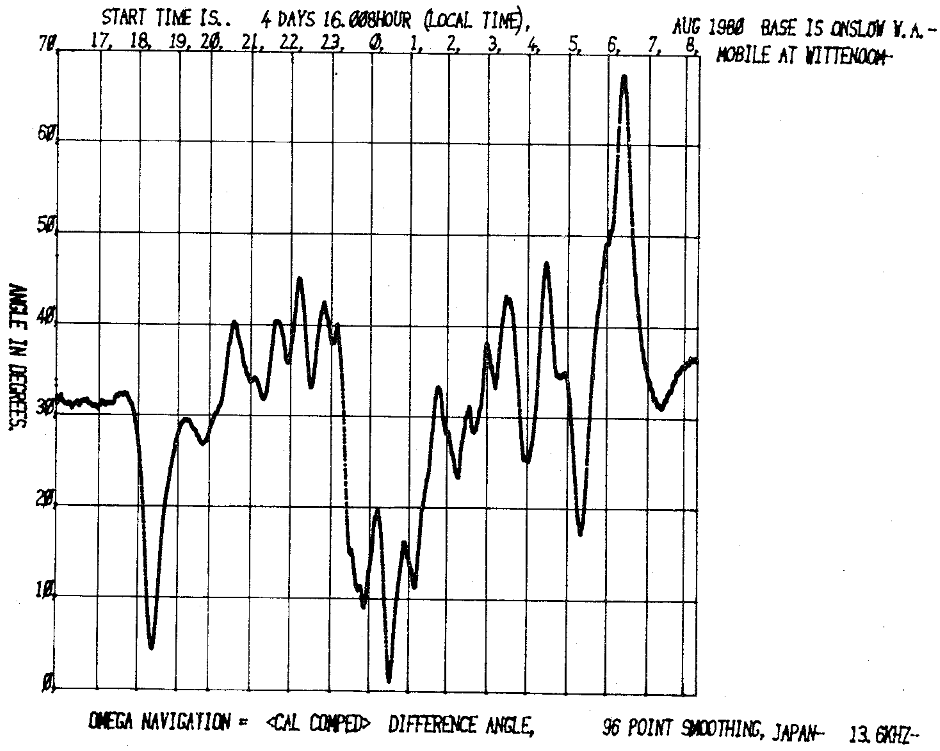


Figure 28. Angular difference (27)-(26)

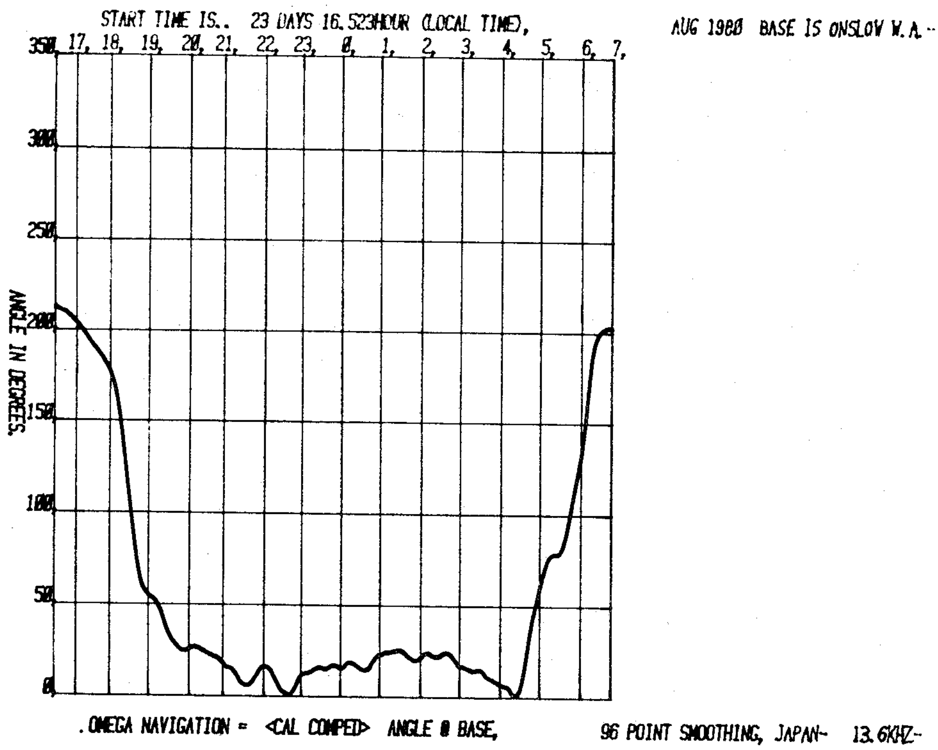


Figure 29. Overnight phase of Japan in Onslow on 13.6 kHz 23/24 August

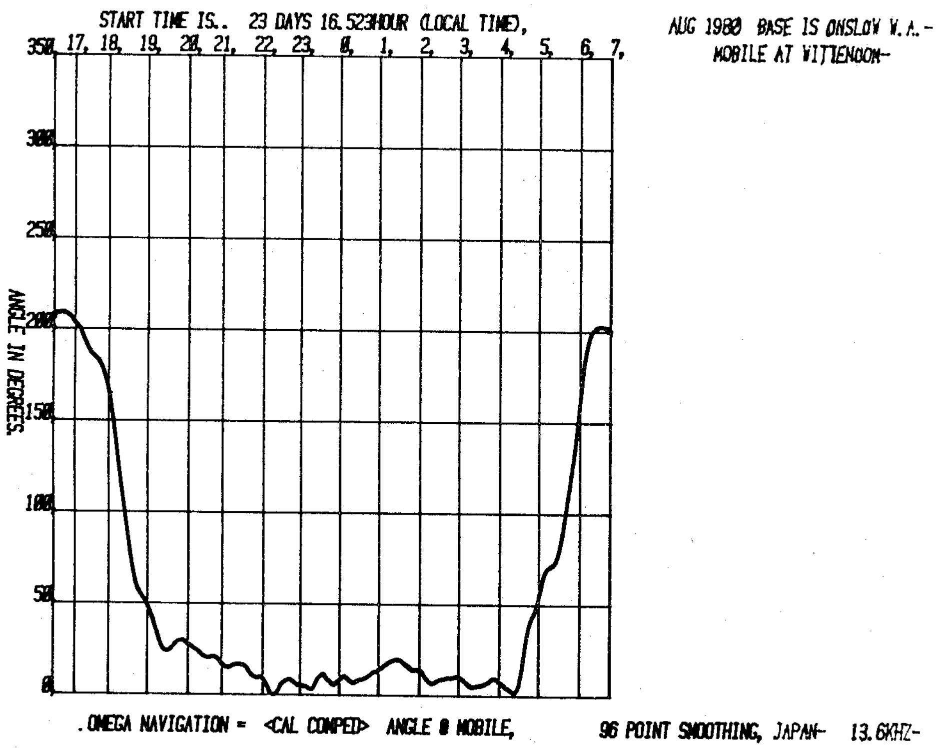


Figure 30. Overnight phase of Japan in Wittenoom on 13.6 kHz 23/24 August

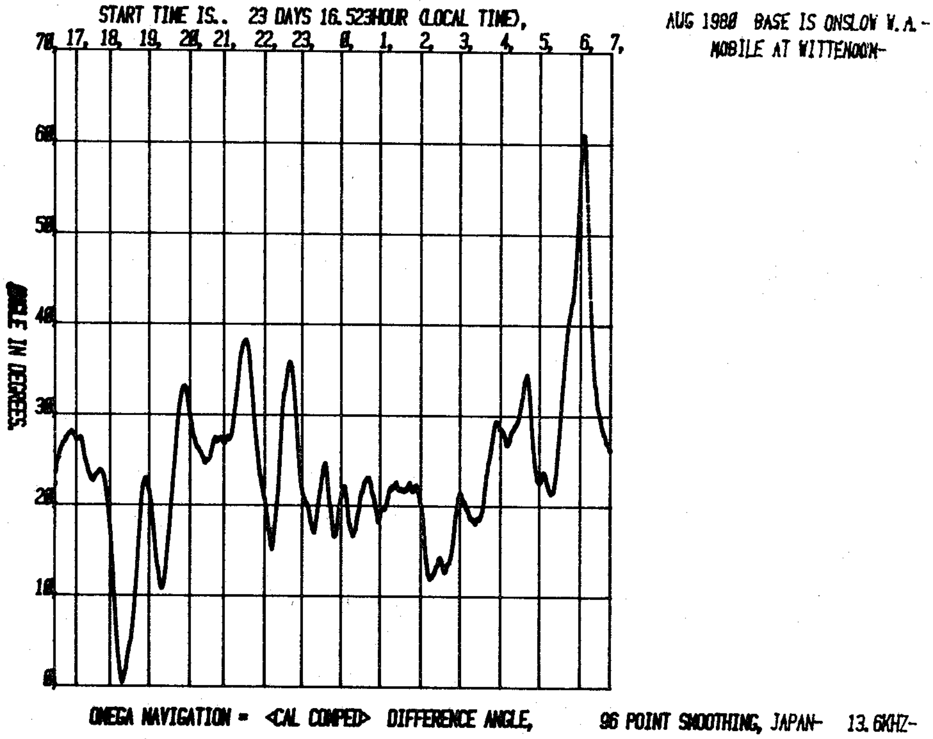


Figure 31. Angular difference (30)-(29)

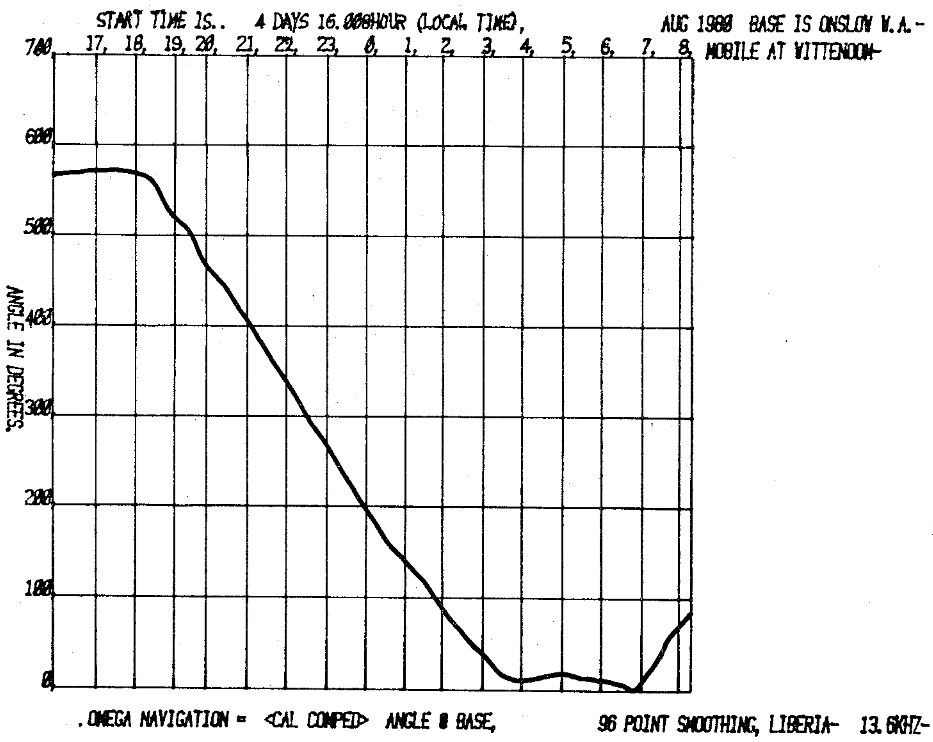


Figure 32. Overnight phase of Liberia in Onslow on 13.6 kHz 4/5 August

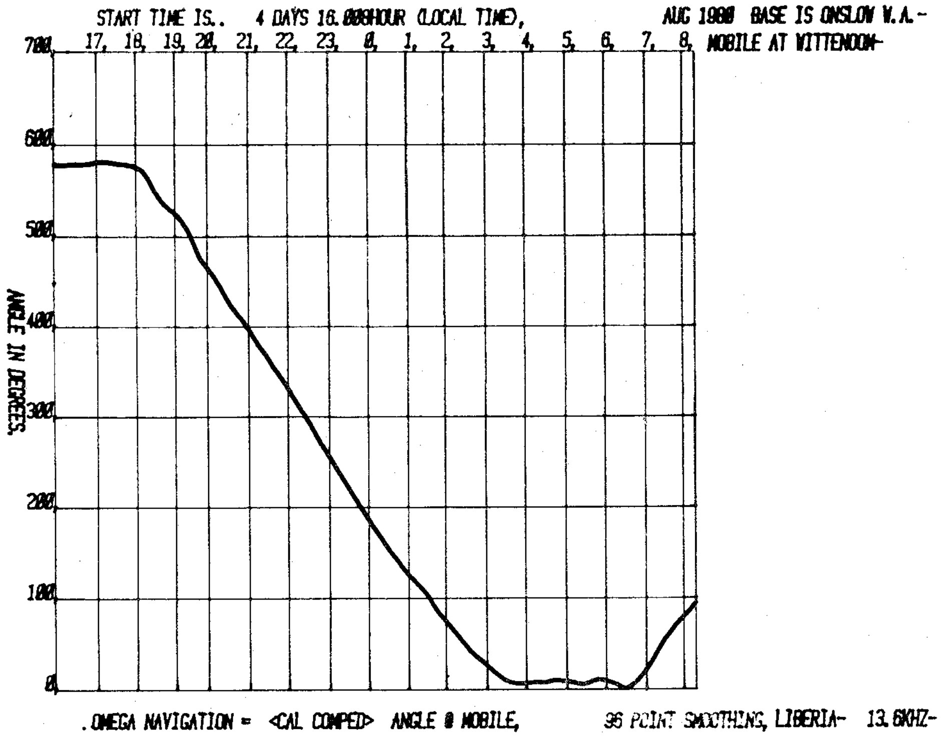


Figure 33. Overnight phase of Liberia in Wittenoom on 13.6 kHz 4/5 August

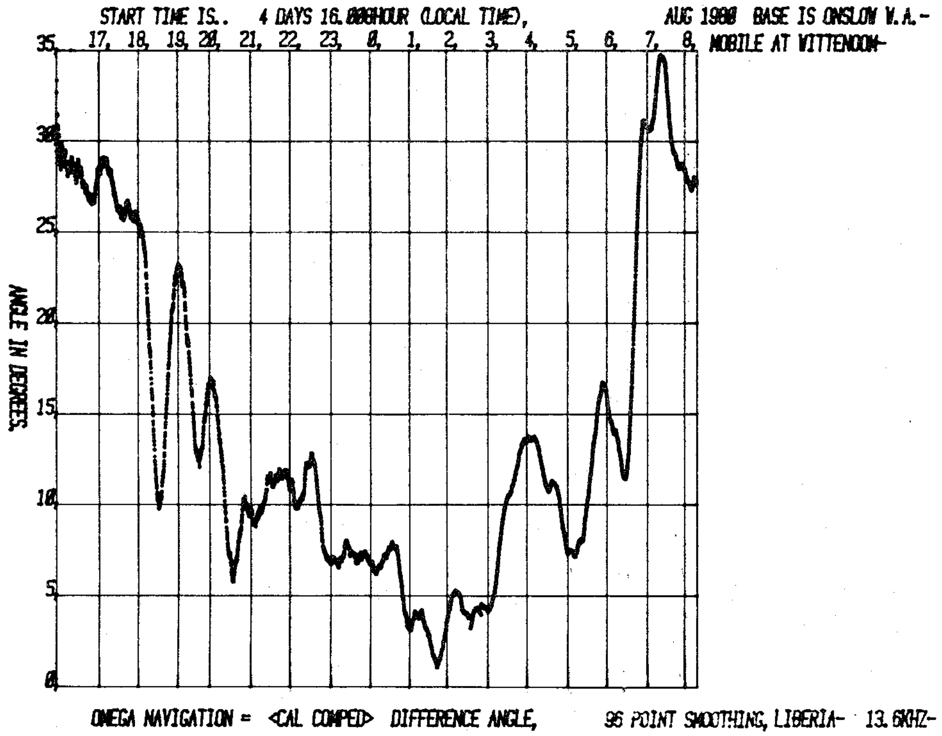


Figure 34. Angular difference (33)-(32)

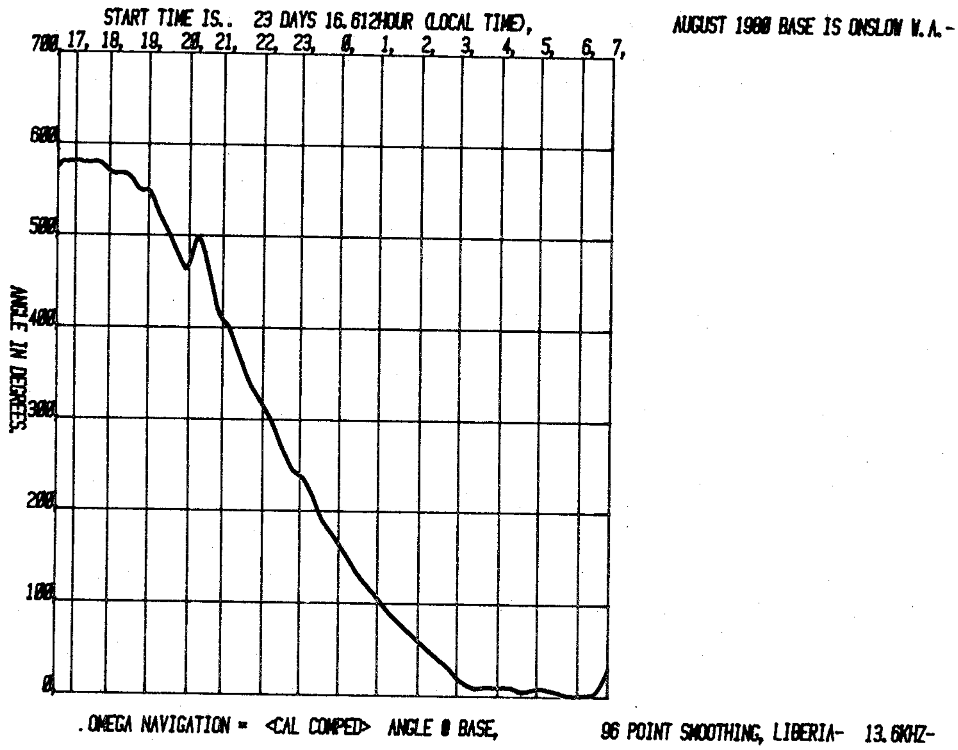


Figure 35. Overnight phase of Liberia in Onslow on 13.6 kHz 23/24 August

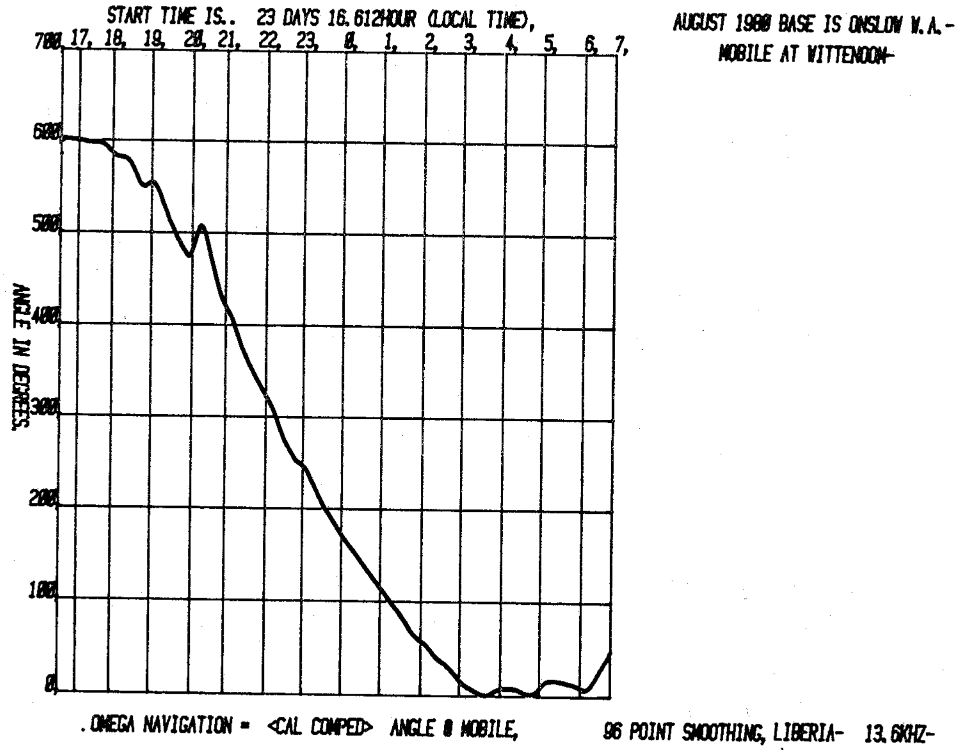


Figure 36. Overnight phase of Liberia in Wittenoom on 13.6 kHz 23/24 August

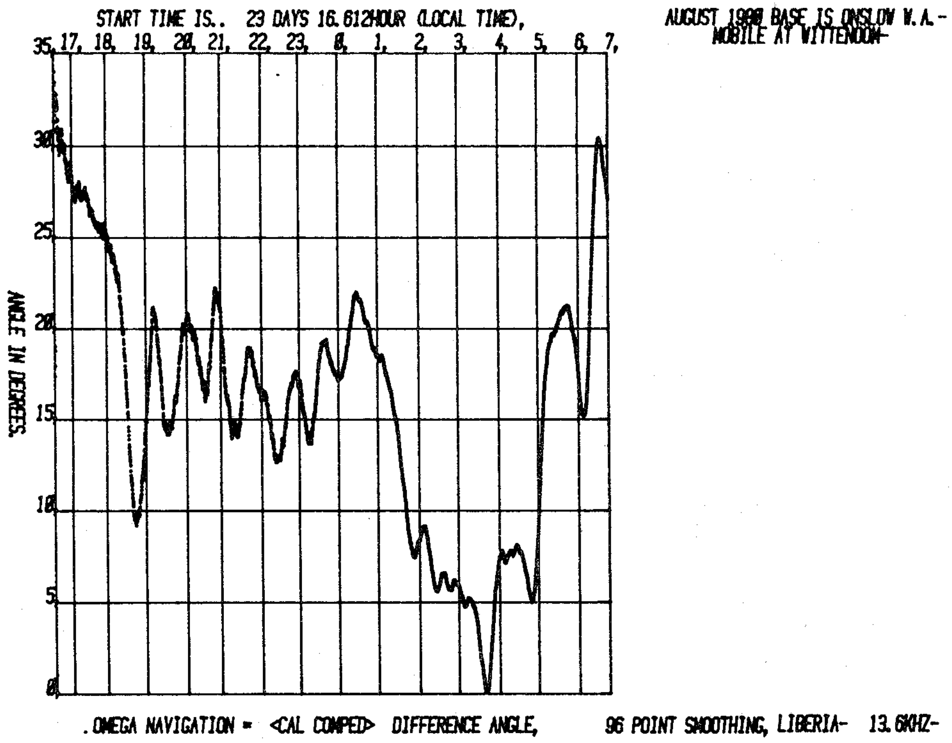


Figure 37. Angular difference (36)-(35)

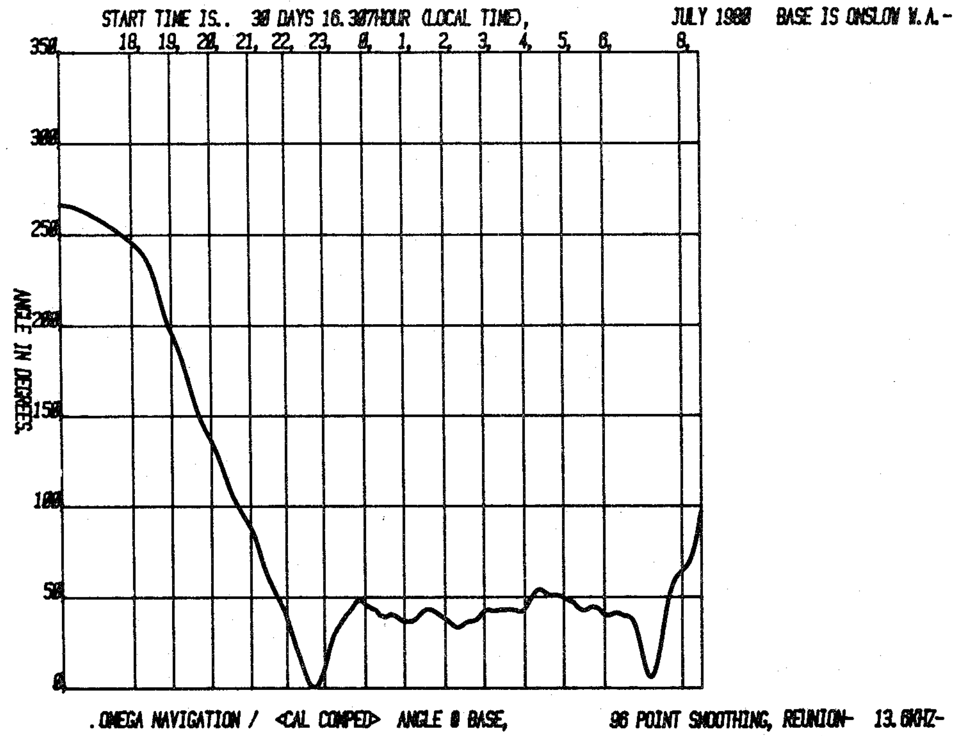


Figure 38. Overnight phase of Reunion in Onslow on 13.6 kHz 30/31 July

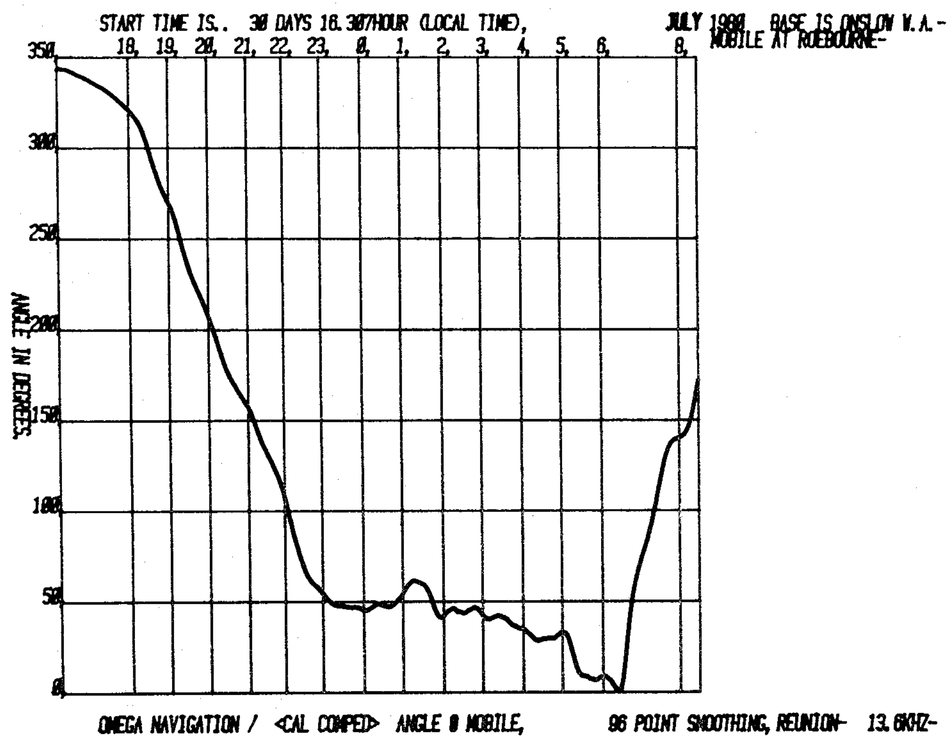


Figure 39. Overnight phase of Reunion in Roebourne on 13.6 kHz 30/31 July

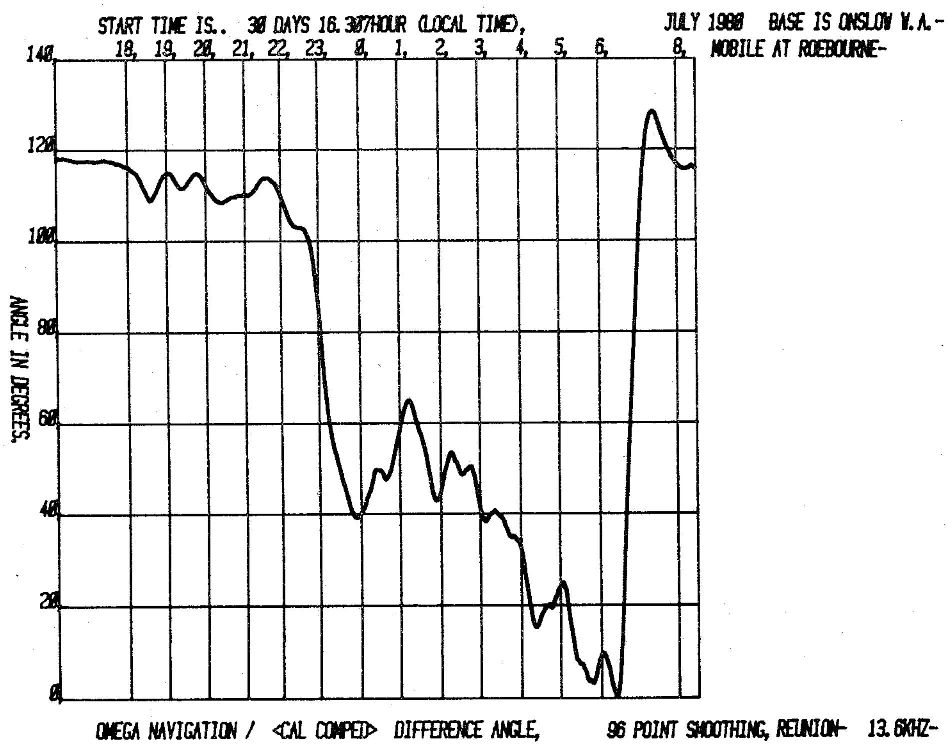


Figure 40. Angular difference (39)-(38)

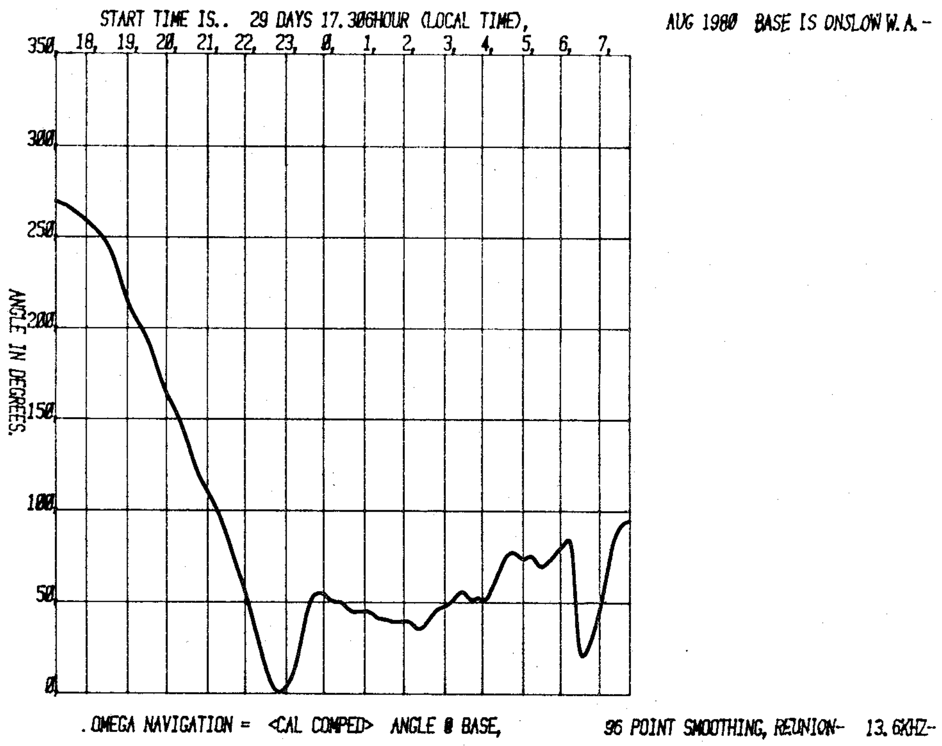


Figure 41. Overnight phase of Reunion in Onslow on 13.6 kHz 29/30 August

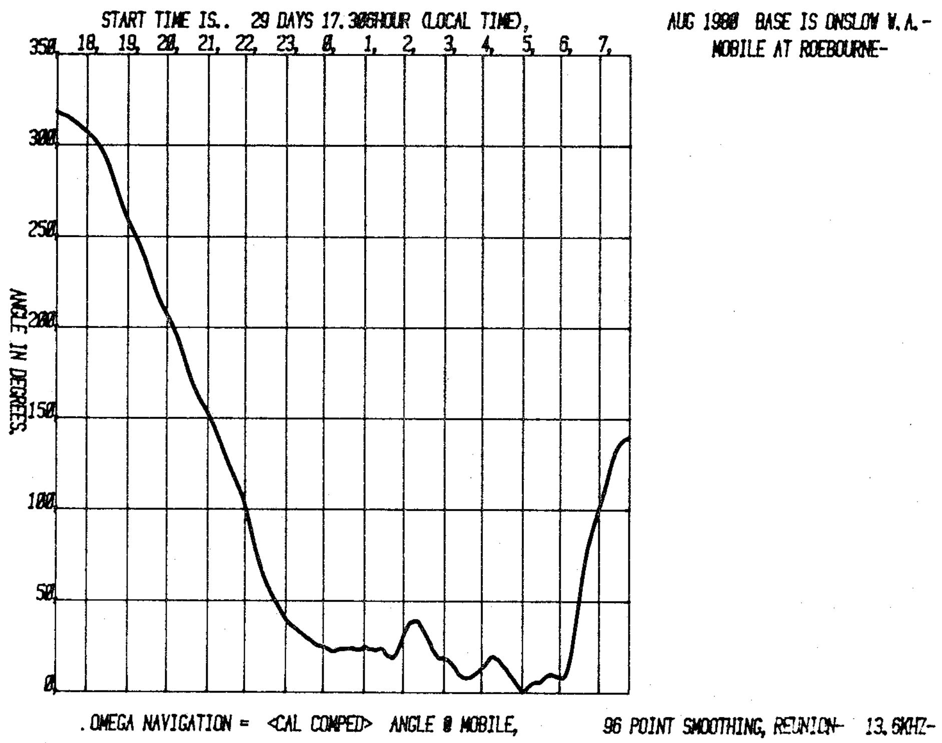


Figure 42. Overnight phase of Reunion in Roebourne on 13.6 kHz 29/30 August

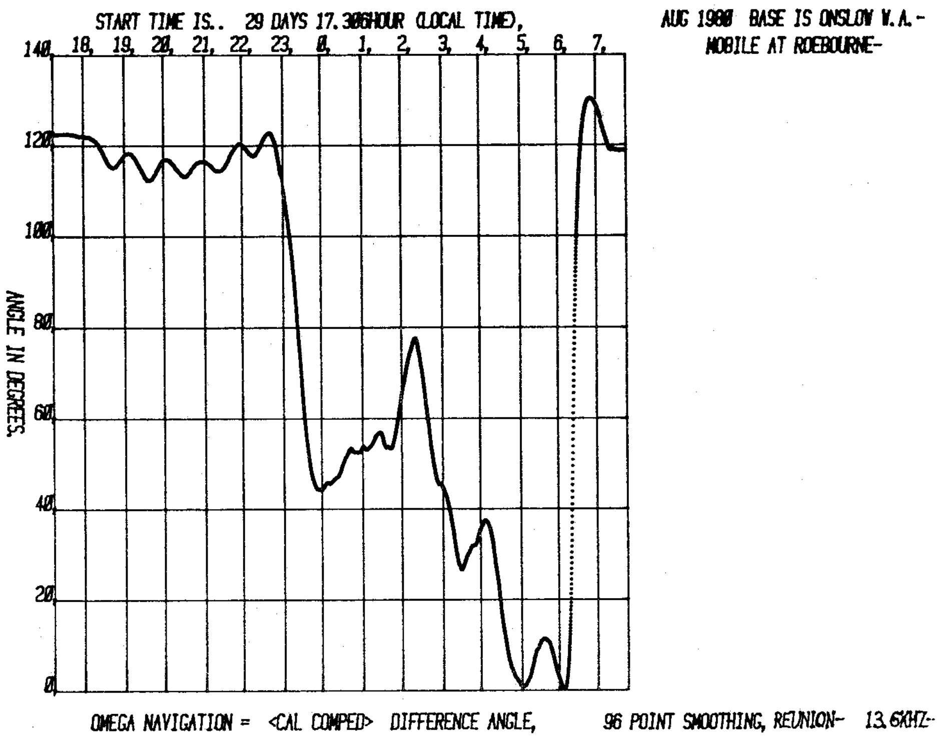


Figure 43. Angular difference (42)-(41)

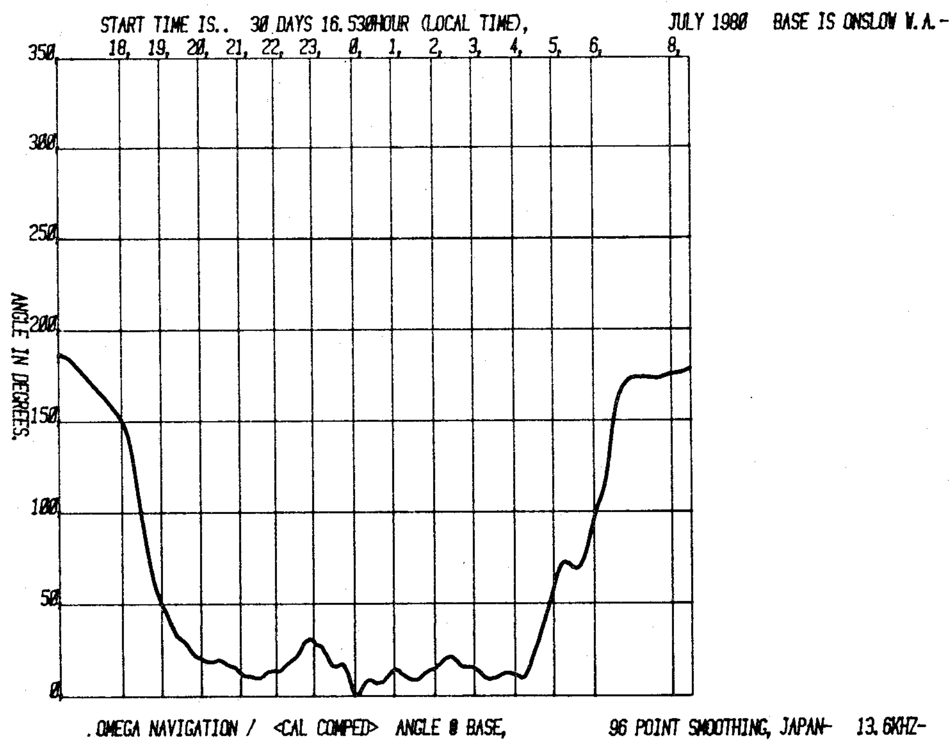


Figure 44. Overnight phase of Japan in Onslow on 13.6 kHz 30/31 July

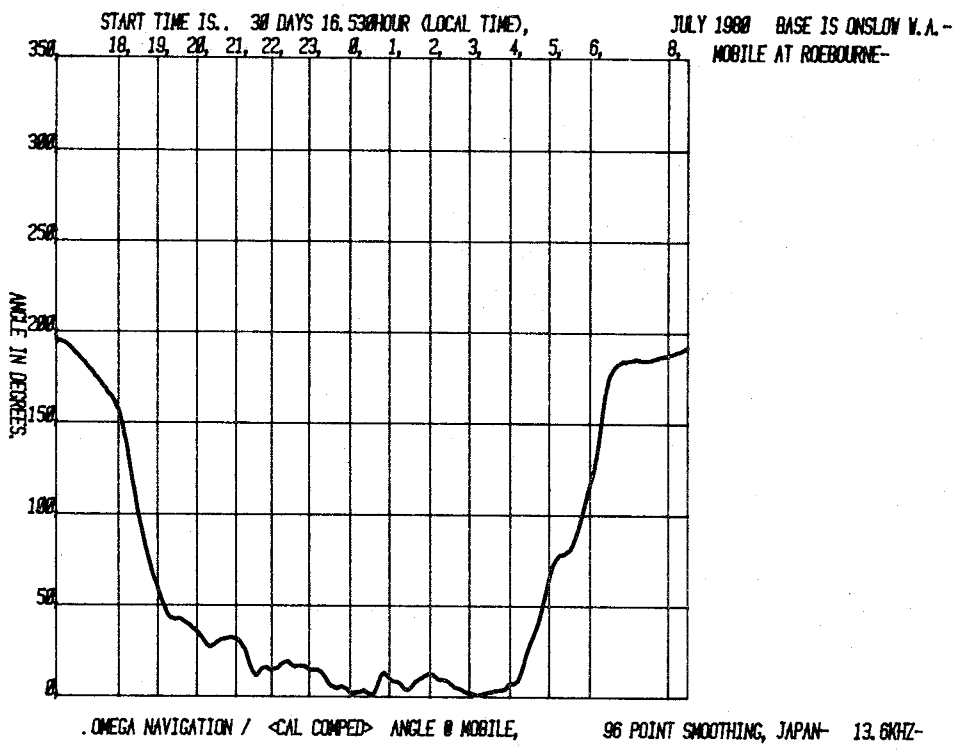


Figure 45. Overnight phase of Japan in Roebourne on 13.6 kHz 30/31 July

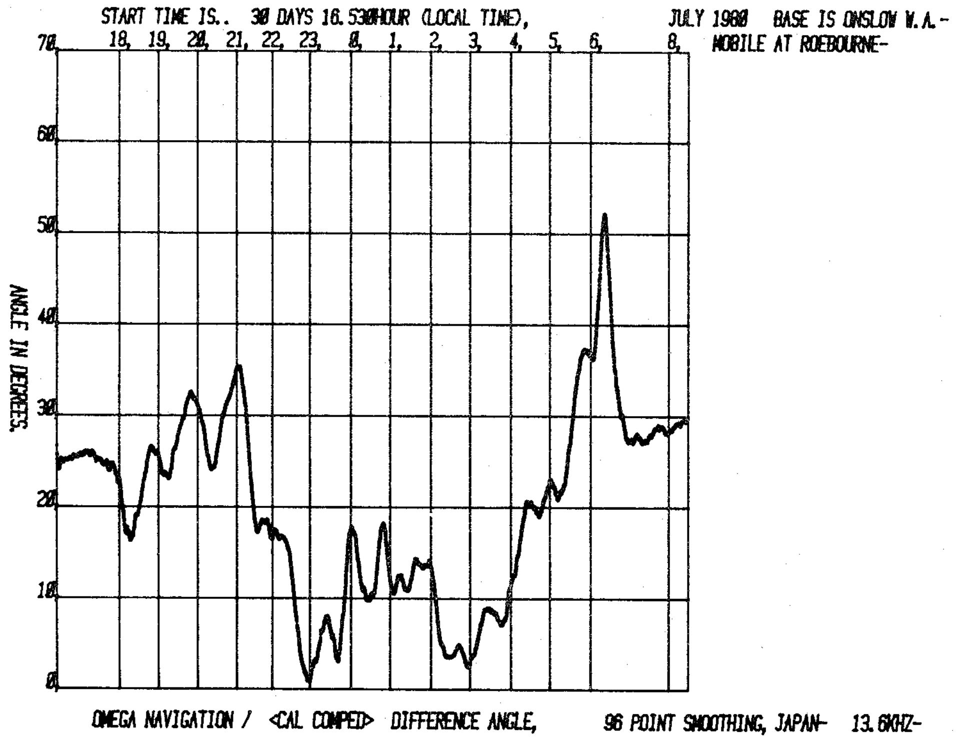


Figure 46. Angular difference (45)-(44)

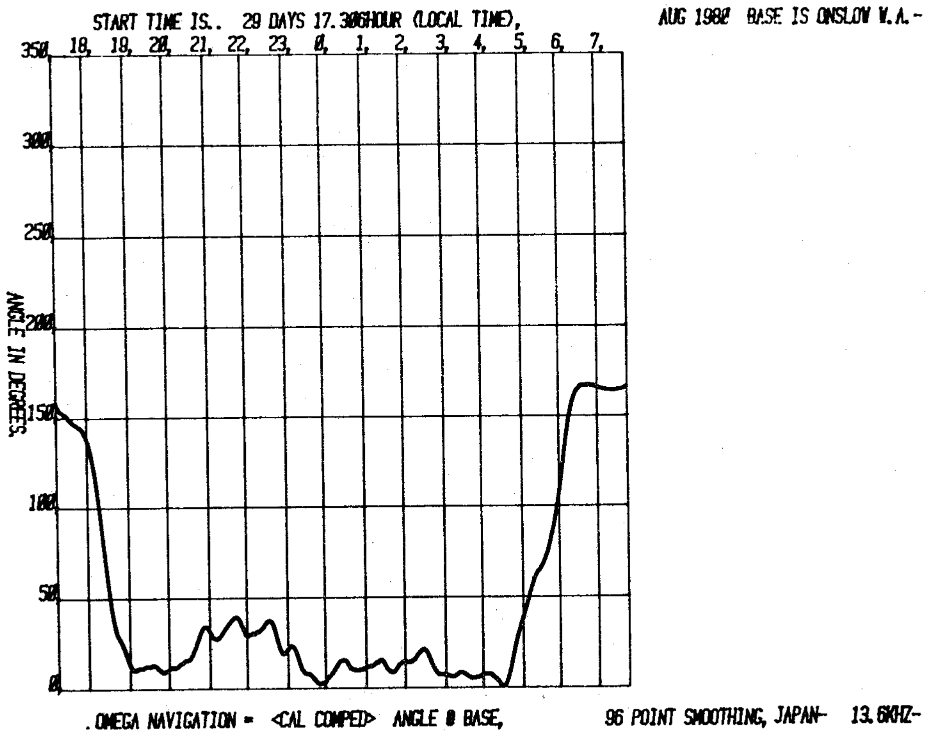


Figure 47. Overnight phase of Japan in Onslow on 13.6 kHz 29/30 August

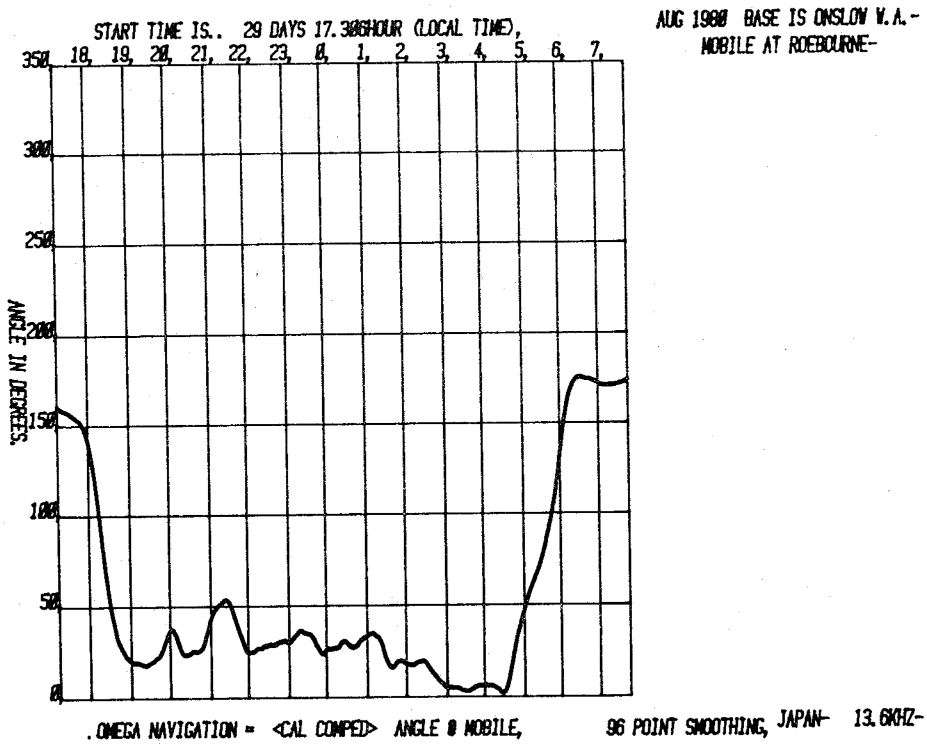


Figure 48. Overnight phase of Japan in Roebourne on 13.6 kHz 29/30 August

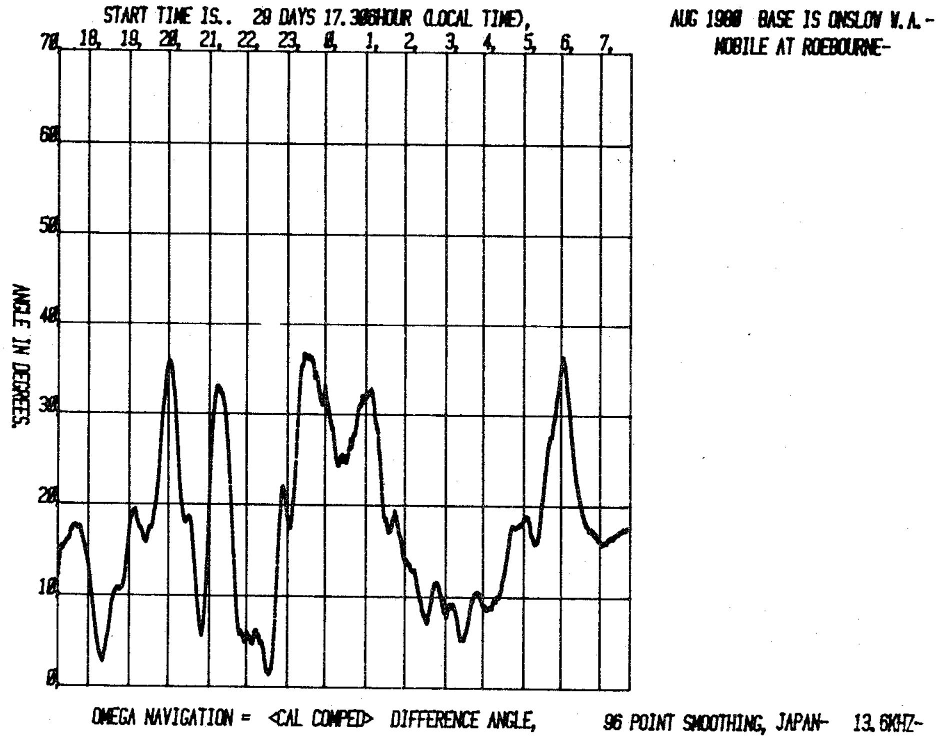


Figure 49. Angular difference (48)-(47)

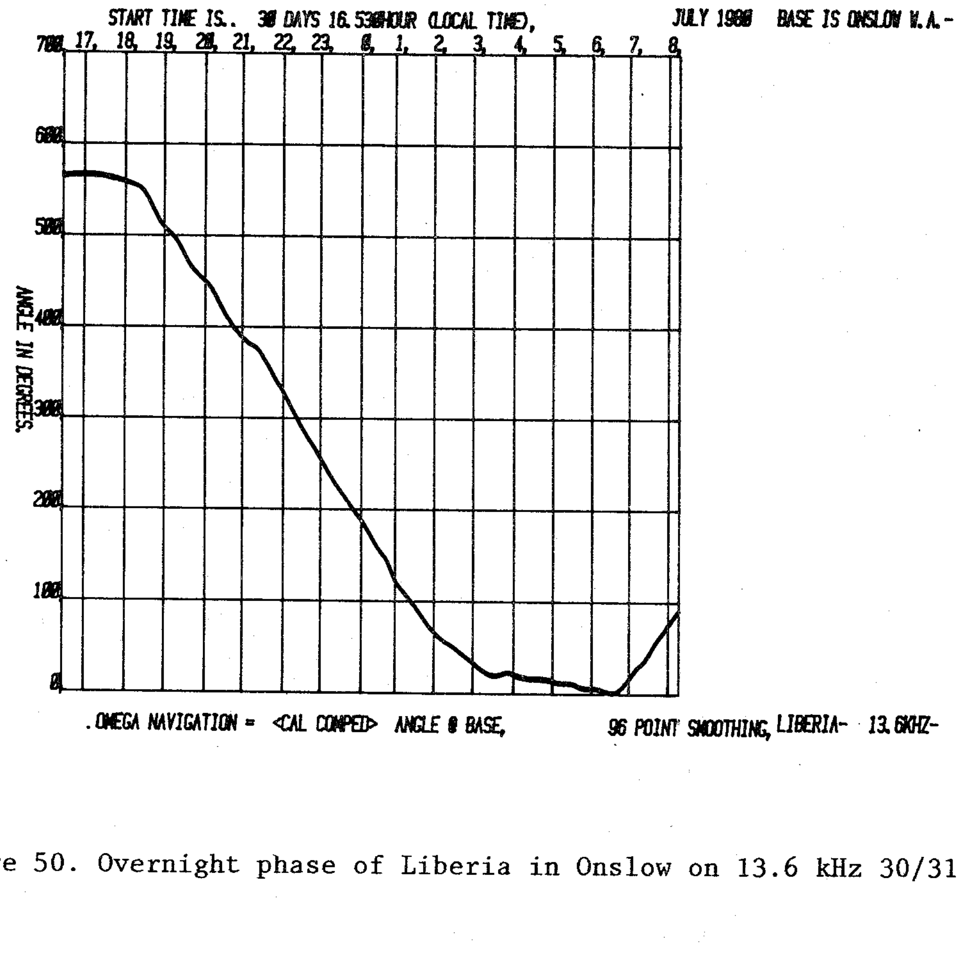


Figure 50. Overnight phase of Liberia in Onslow on 13.6 kHz 30/31 July

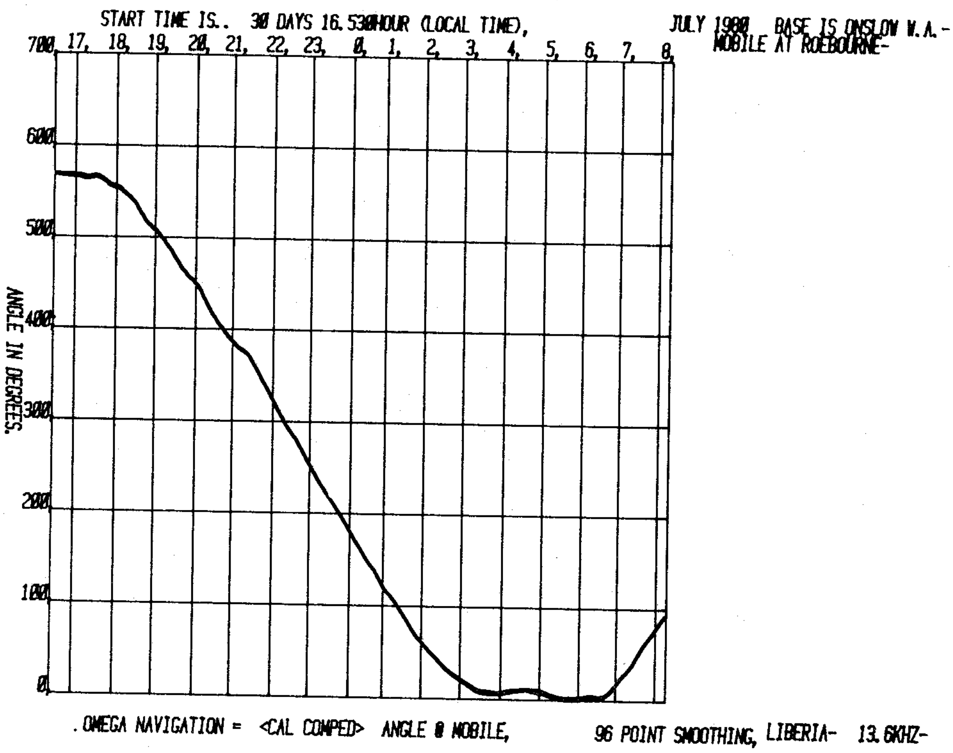


Figure 51. Overnight phase of Liberia in Roebourne on 13.6 kHz 30/31 July

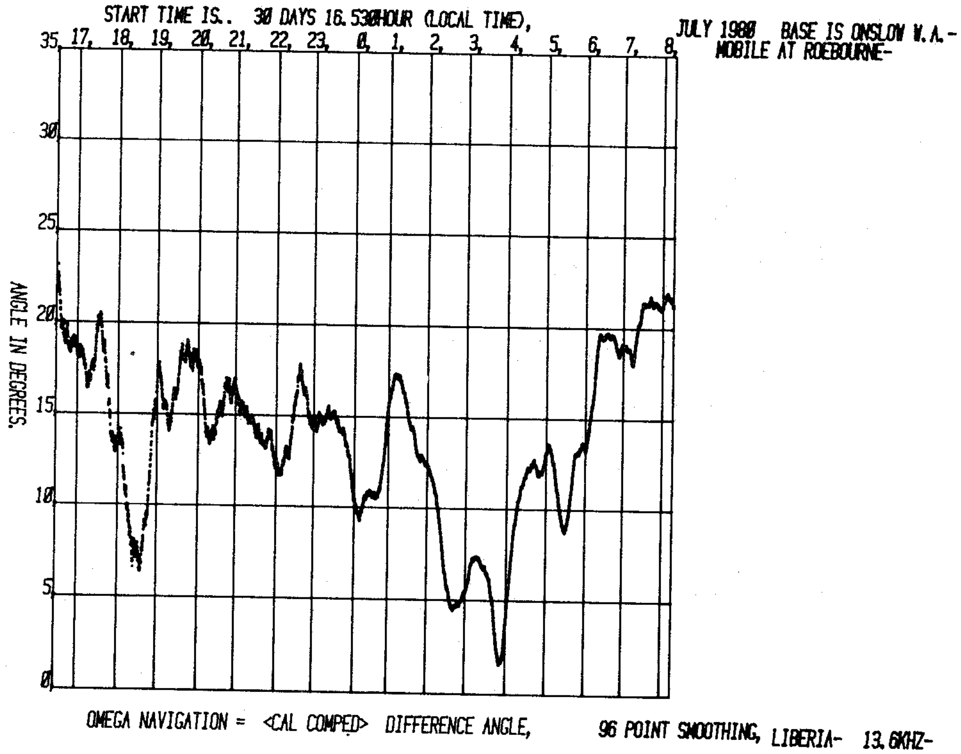


Figure 52. Angular difference (51)-(50)

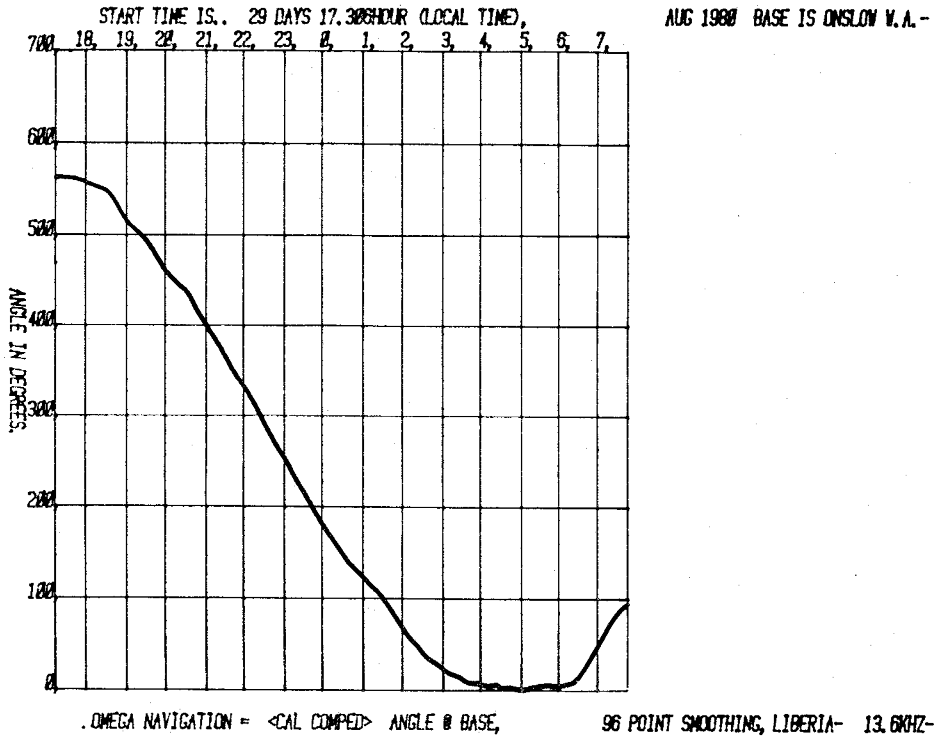


Figure 53. Overnight phase of Liberia in Onslow on 13.6 kHz 29/30 August

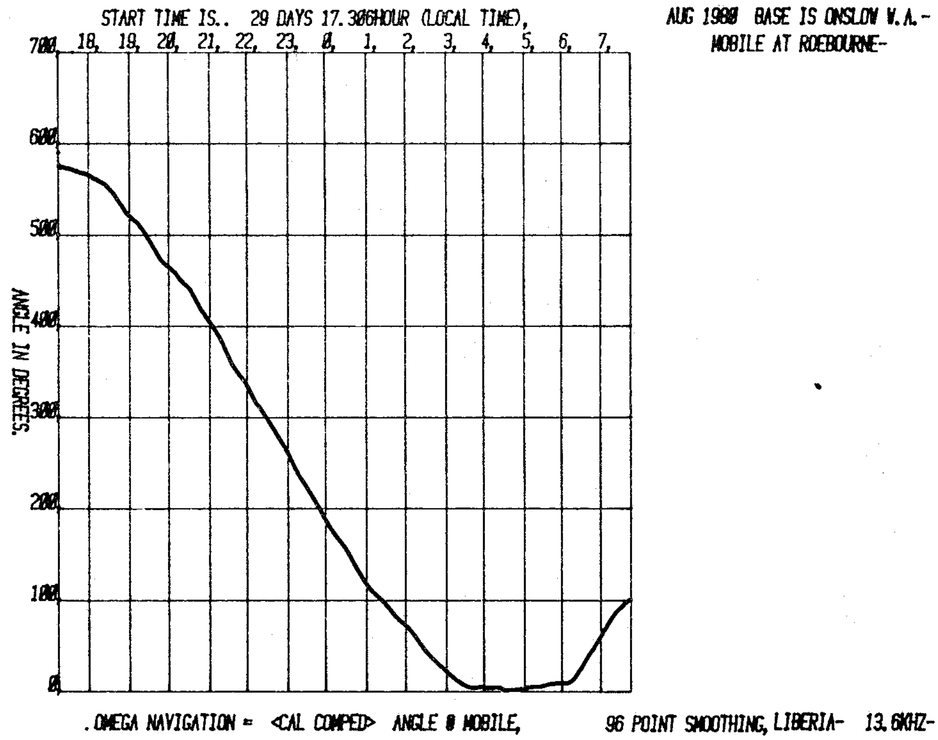


Figure 54. Overnight phase of Liberia in Roebourne on 13.6 kHz 29/30 August

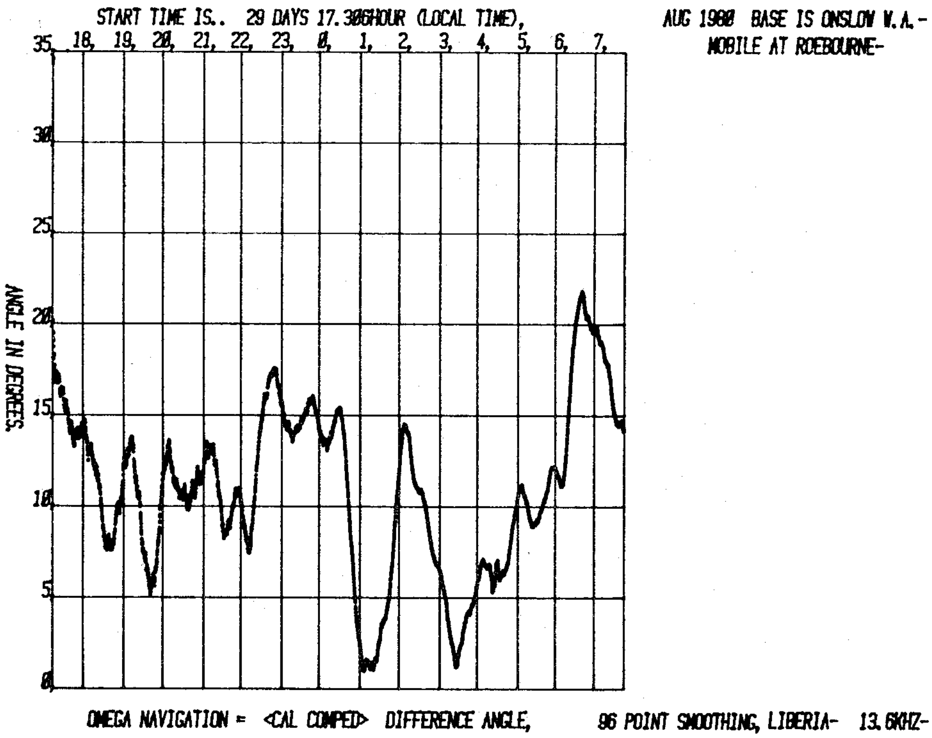


Figure 55. Angular difference (54)-(53)

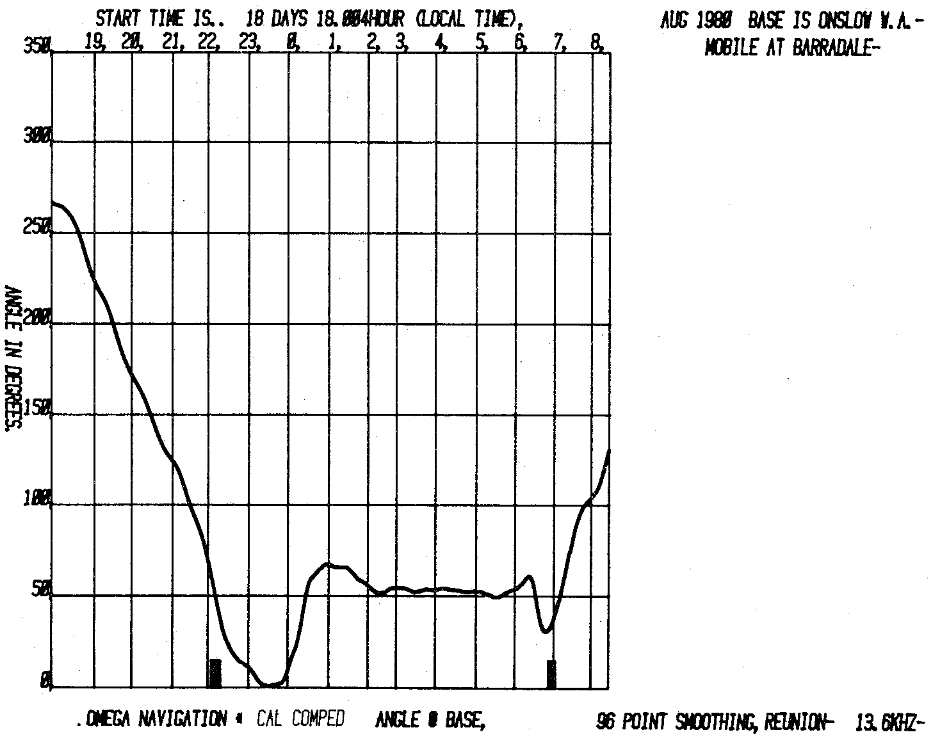


Figure 56. Overnight phase of Reunion in Onslow on 13.6 kHz 18/19 August

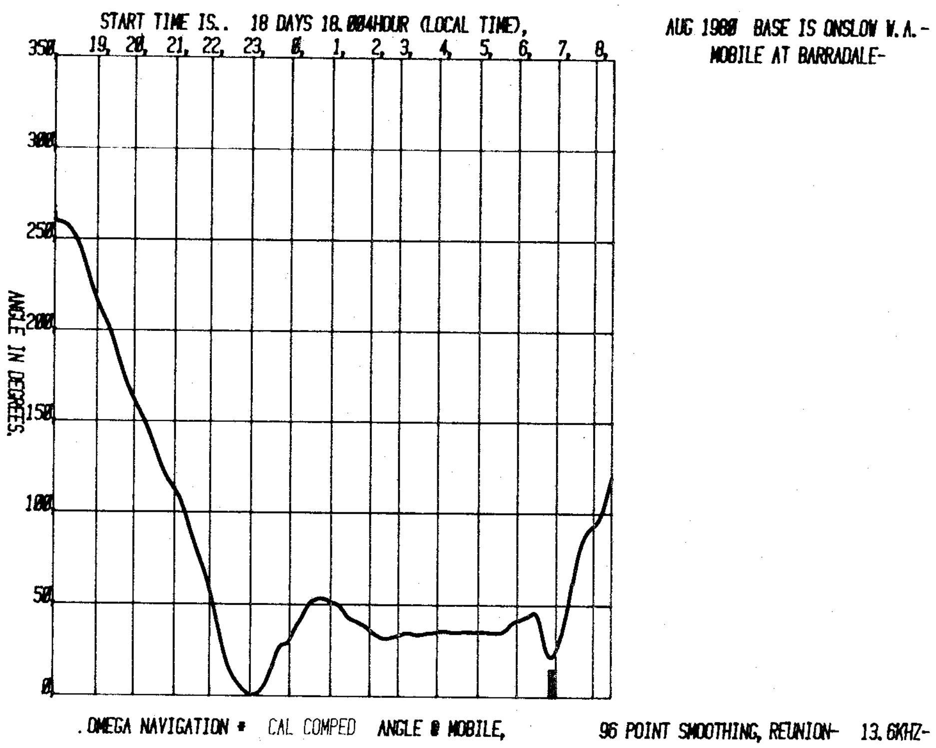


Figure 57. Overnight phase of Reunion in Barradale on 13.6 kHz 18/19 August

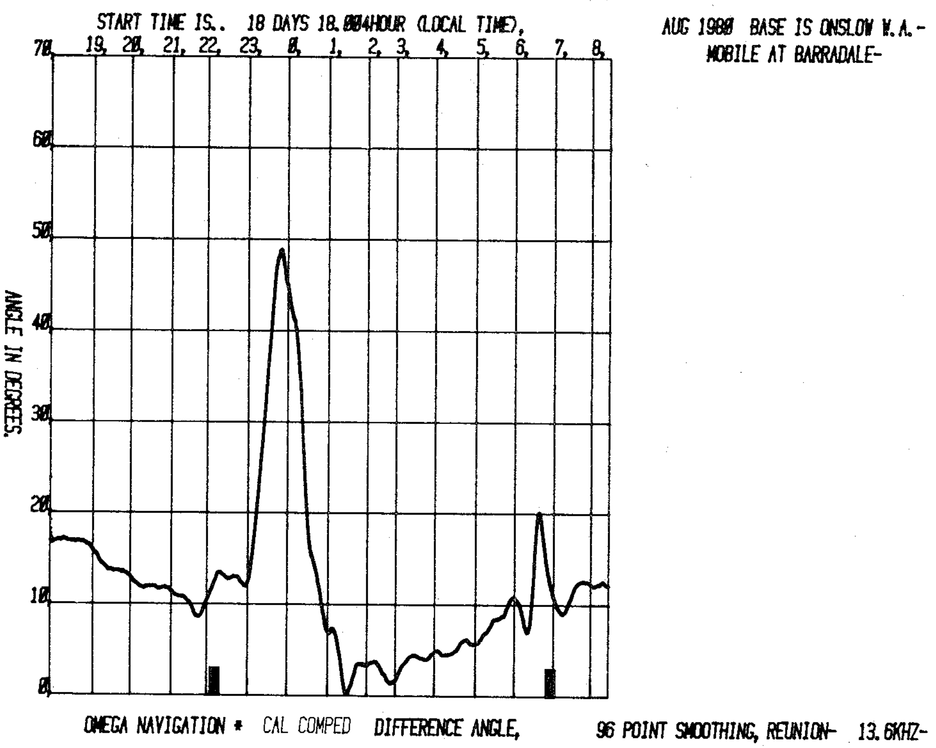


Figure 58. Angular difference (57)-(56)

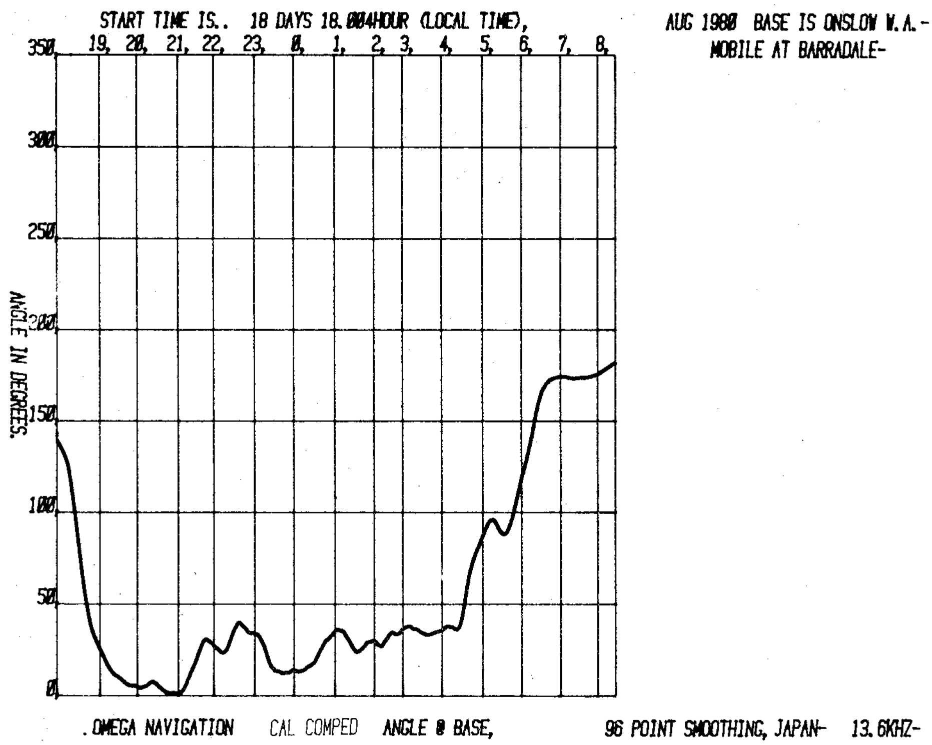


Figure 59. Overnight phase of Japan in Onslow on 13.6 kHz 18/19 August

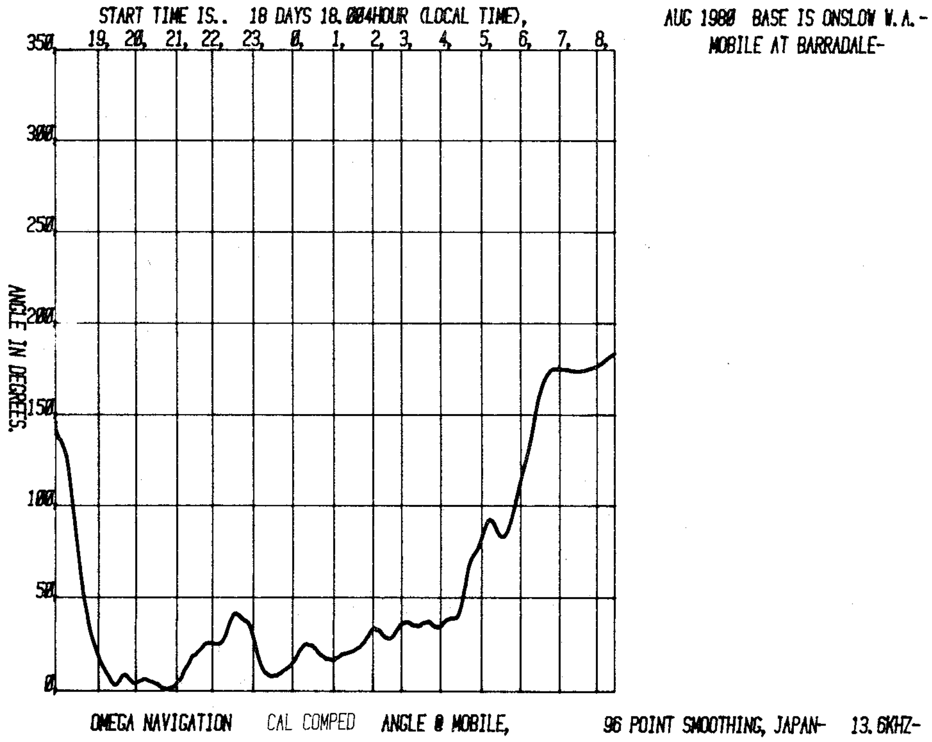


Figure 60. Overnight phase of Japan in Barradale on 13.6 kHz 18/19 August

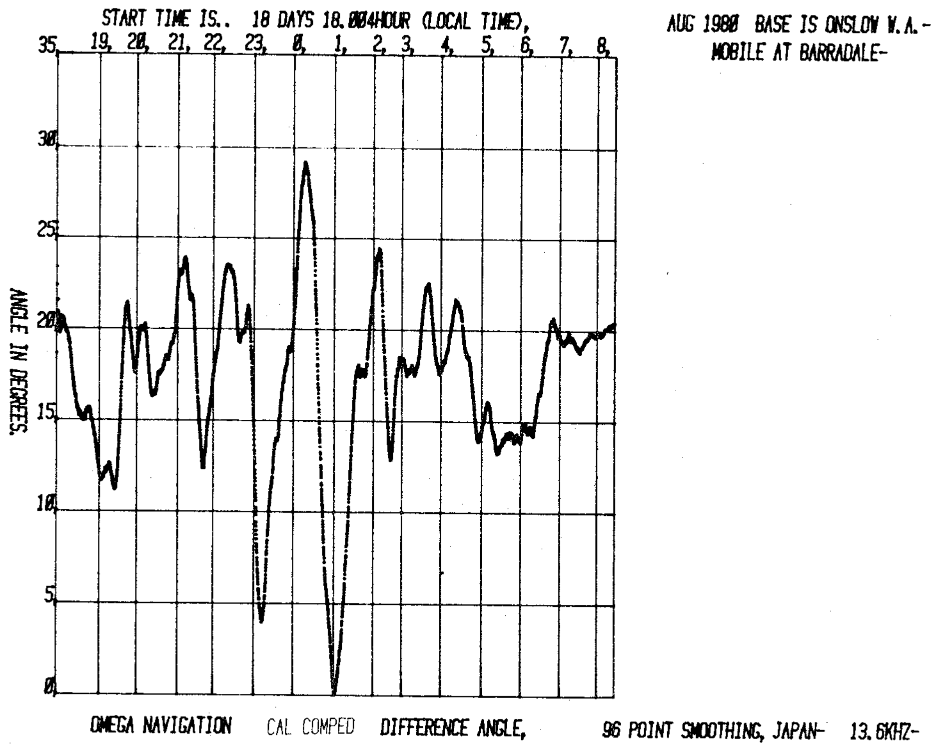


Figure 61. Angular difference (60)-(59)

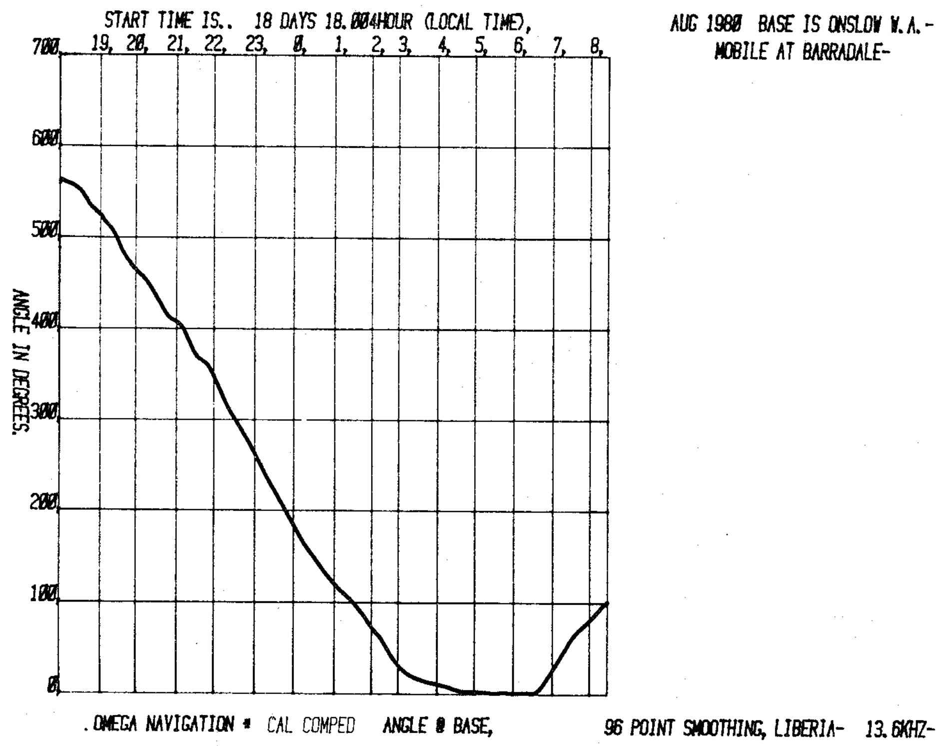


Figure 62. Overnight phase of Liberia in Onslow on 13.6 kHz 18/19 August

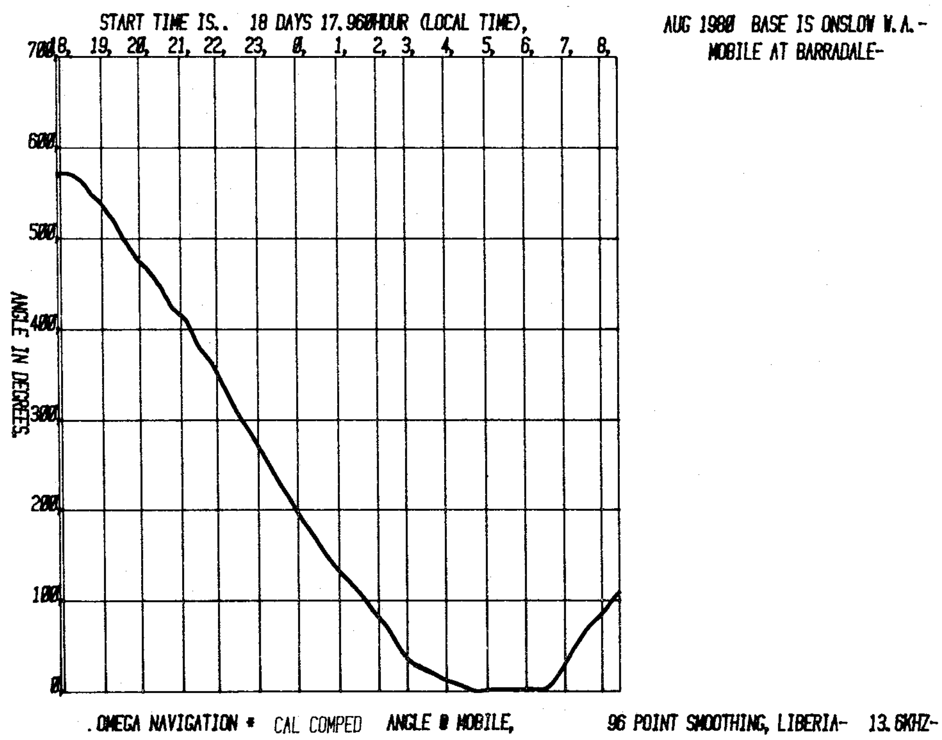


Figure 63. Overnight phase of Liberia in Barradale on 13.6 kHz 18/19 August

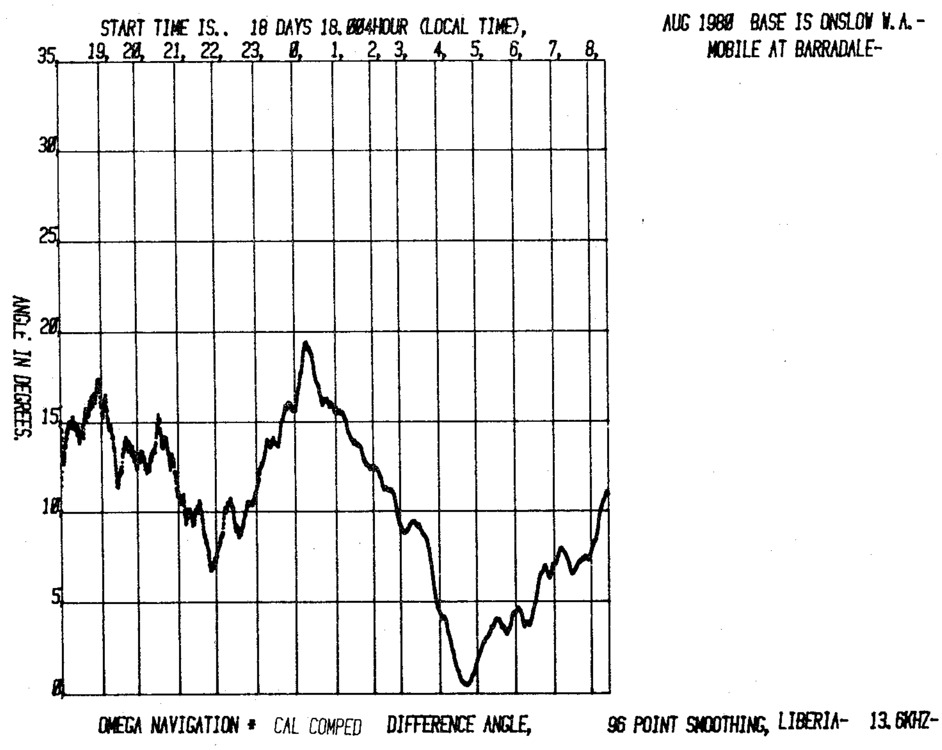


Figure 64. Angular difference (63)-(62)

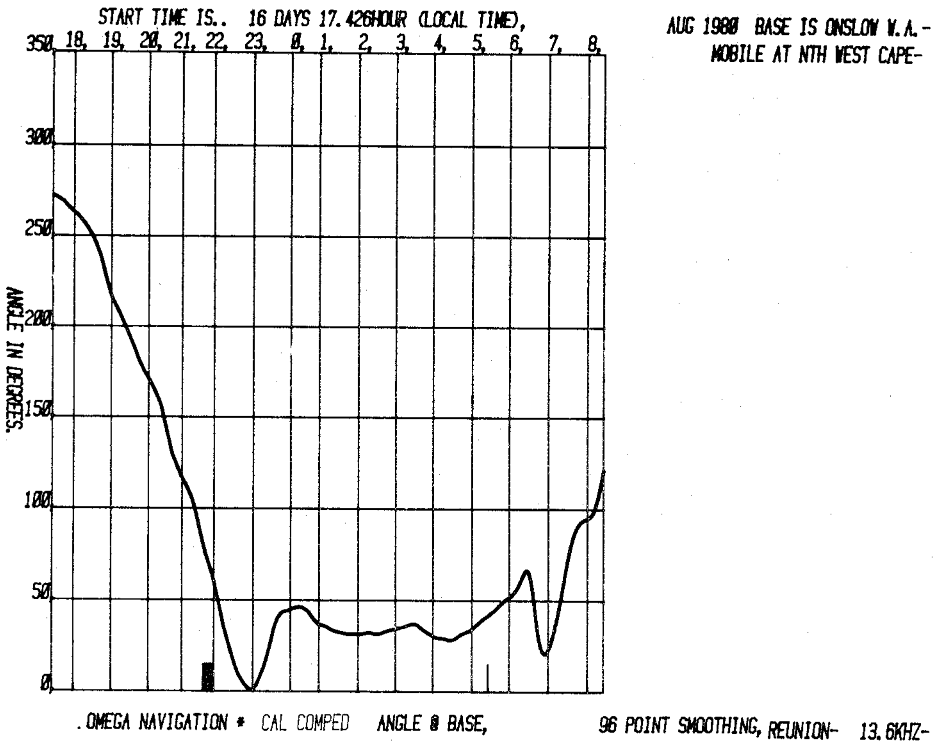


Figure 65. Overnight phase of Reunion in Onslow on 13.6 kHz 16/17 August

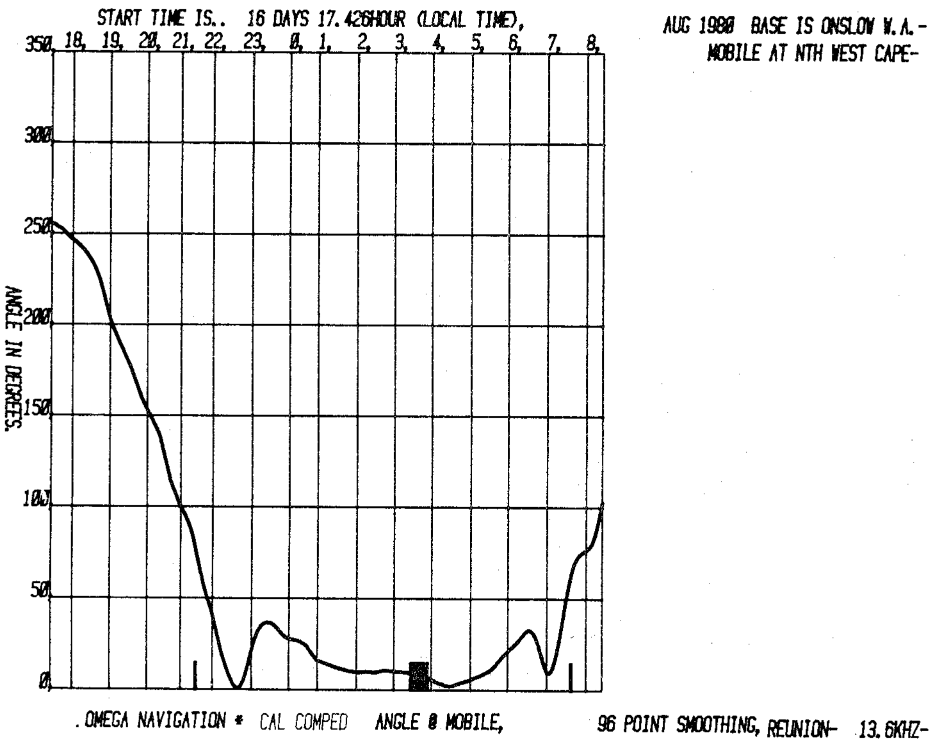


Figure 66. Overnight phase of Reunion in Exmouth on 13.6 kHz 16/17 August

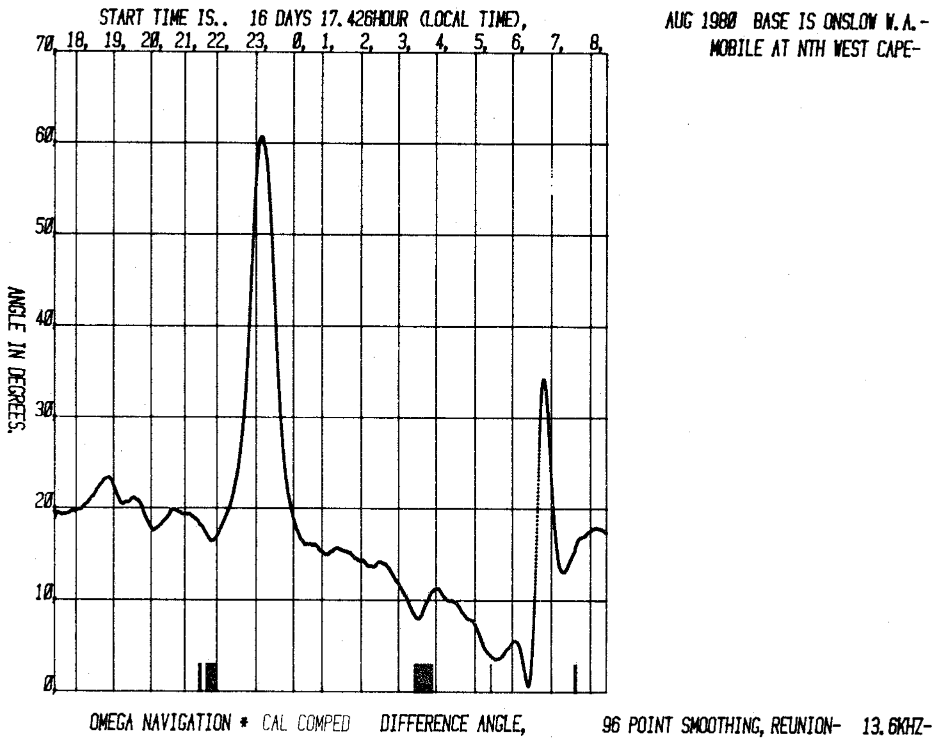


Figure 67. Angular difference (66)-(65)

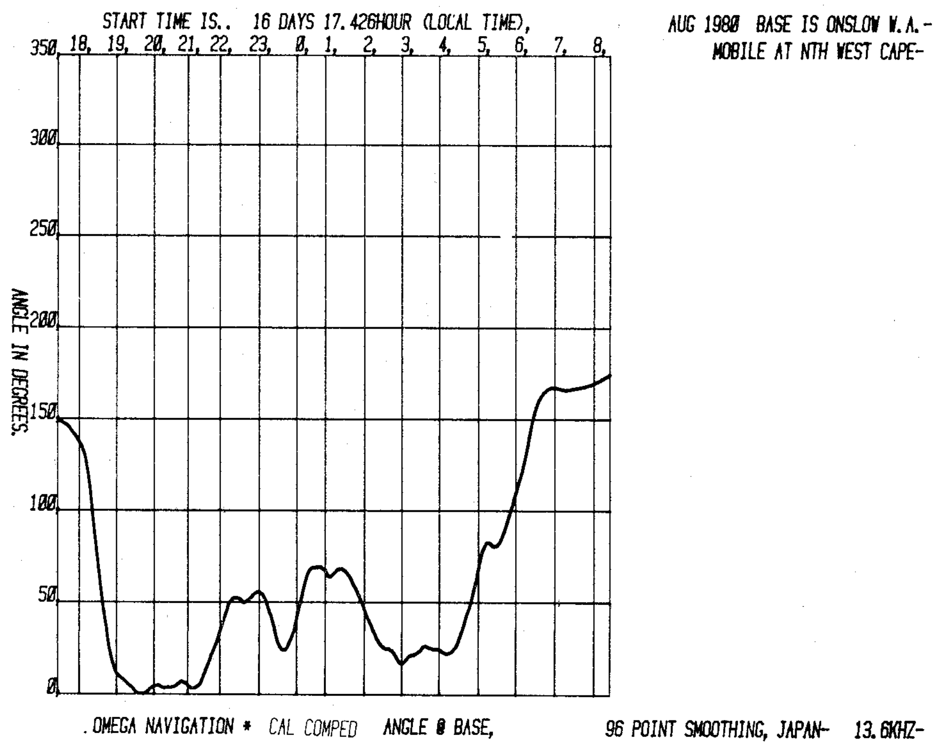


Figure 68. Overnight phase of Japan in Onslow on 13.6 kHz 16/17 August

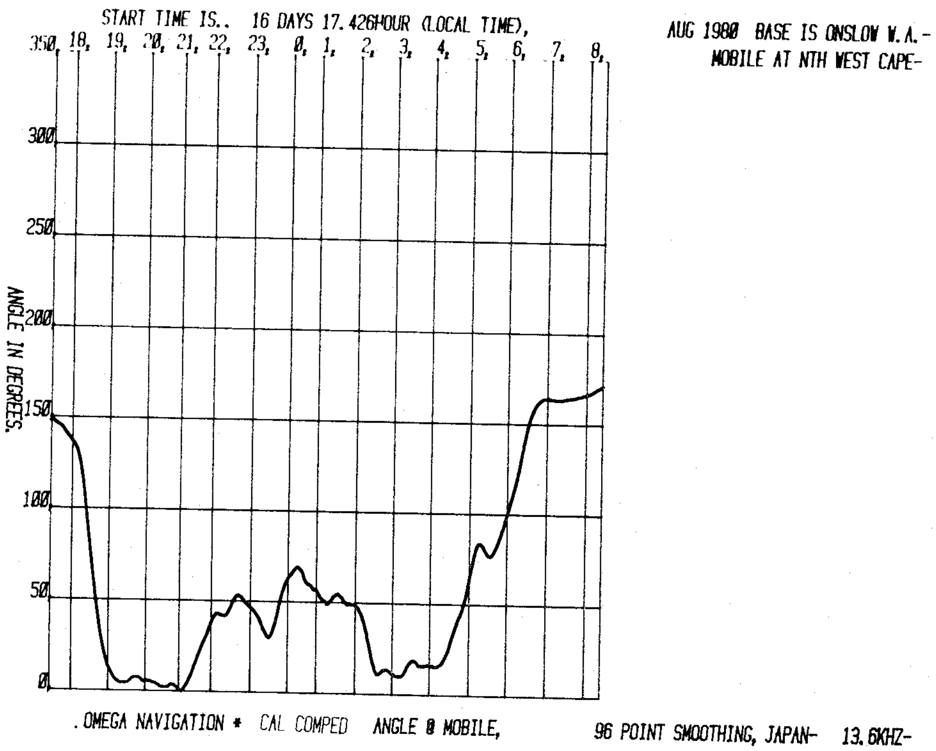


Figure 69. Overnight phase of Japan in Exmouth on 13.6 kHz 16/17 August

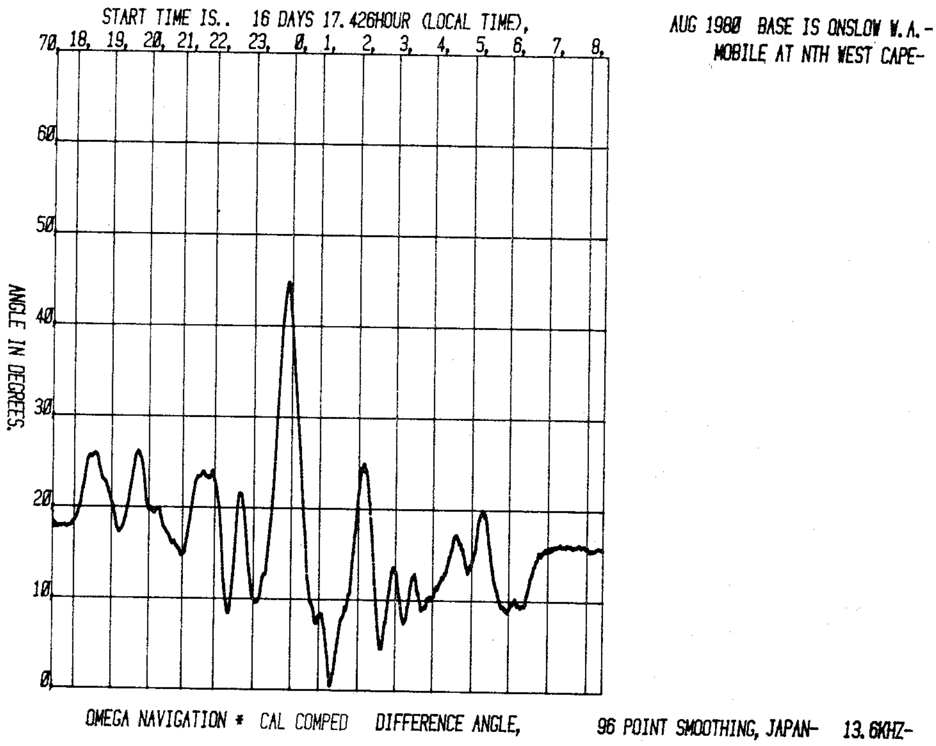


Figure 70. Angular difference (69)-(68)

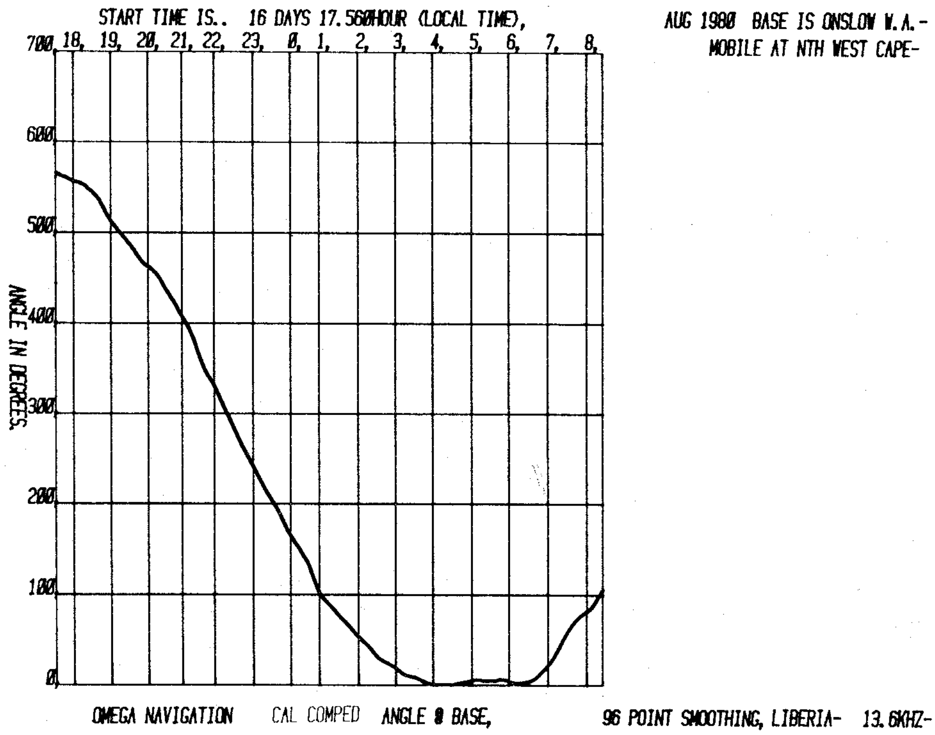


Figure 71. Overnight phase of Liberia in Onslow on 13.6 kHz 16/17 August

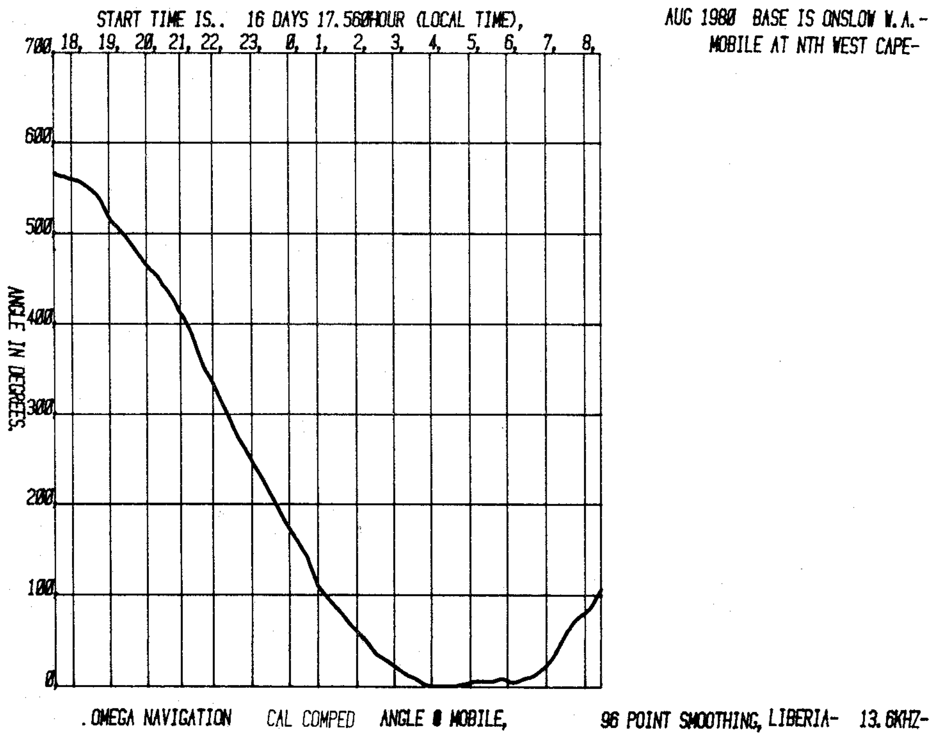


Figure 72. Overnight phase of Liberia in Exmouth on 13.6 kHz 16/17 August

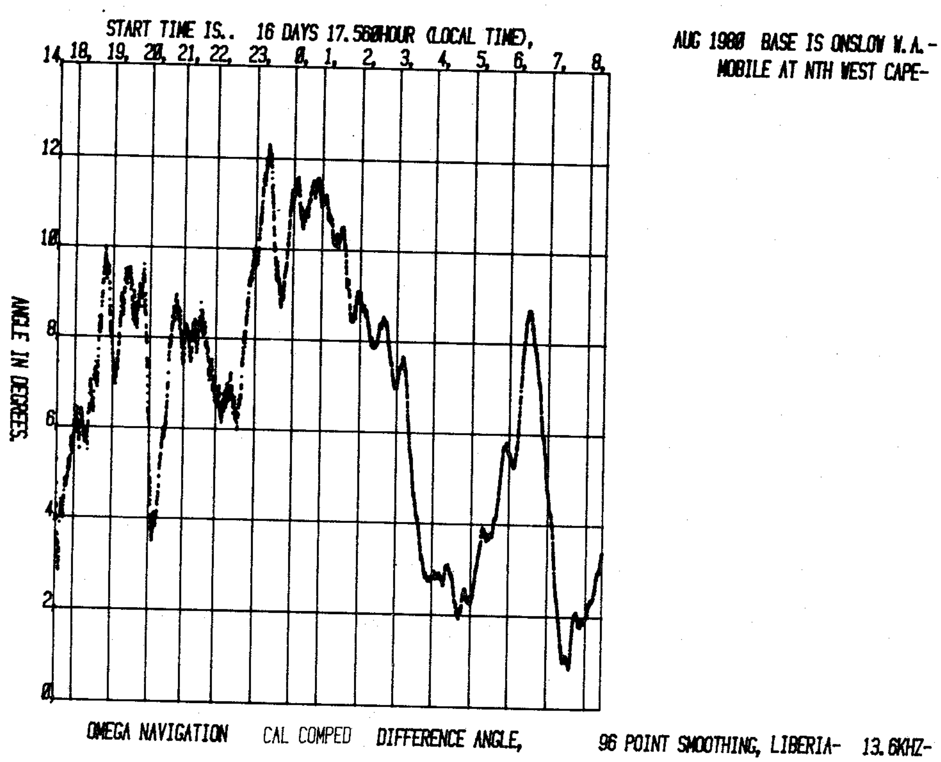


Figure 73. Angular difference (72)-(71)

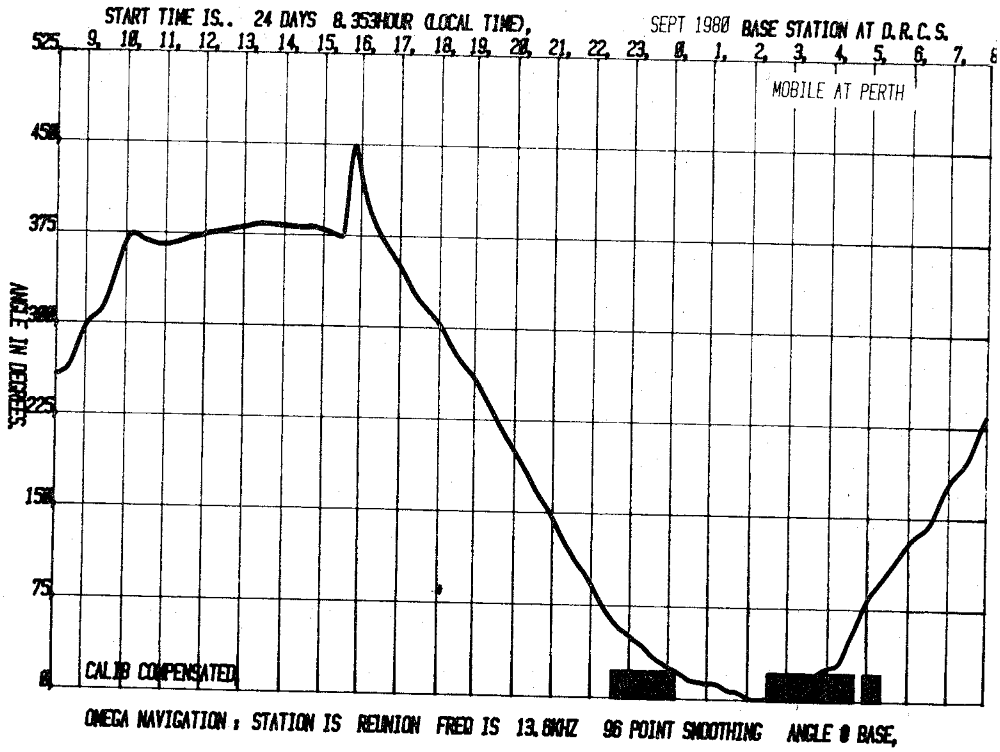


Figure 74. Diurnal phase of Reunion in Adelaide on 13.6 kHz 24/25 September

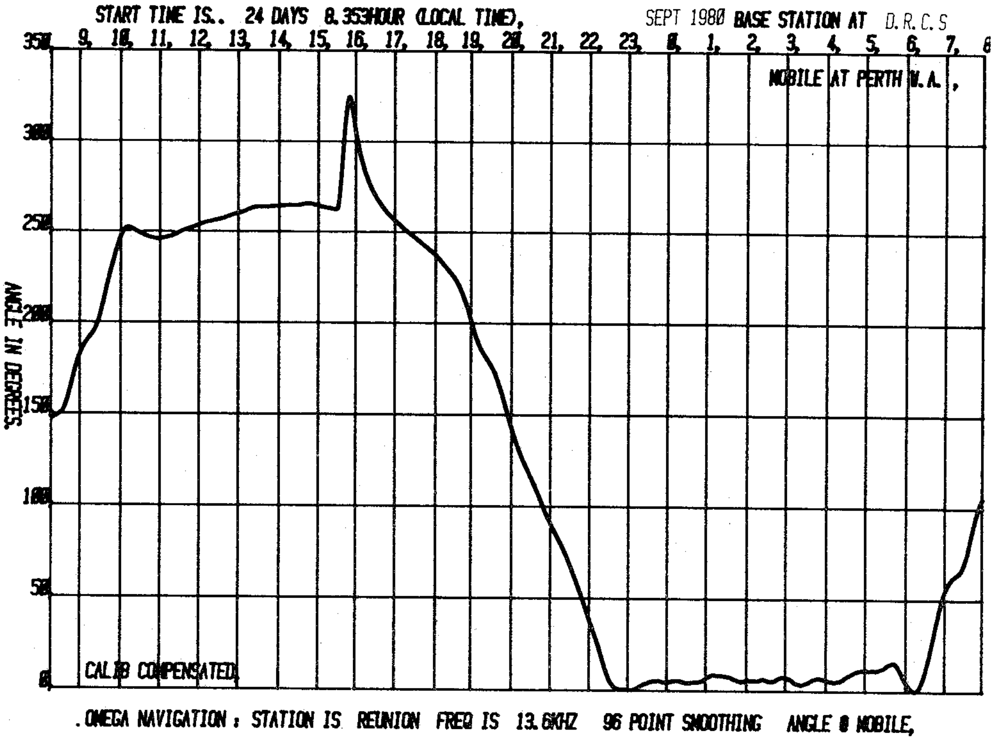


Figure 75. Diurnal phase of Reunion in Perth on 13.6 kHz 24/25 September

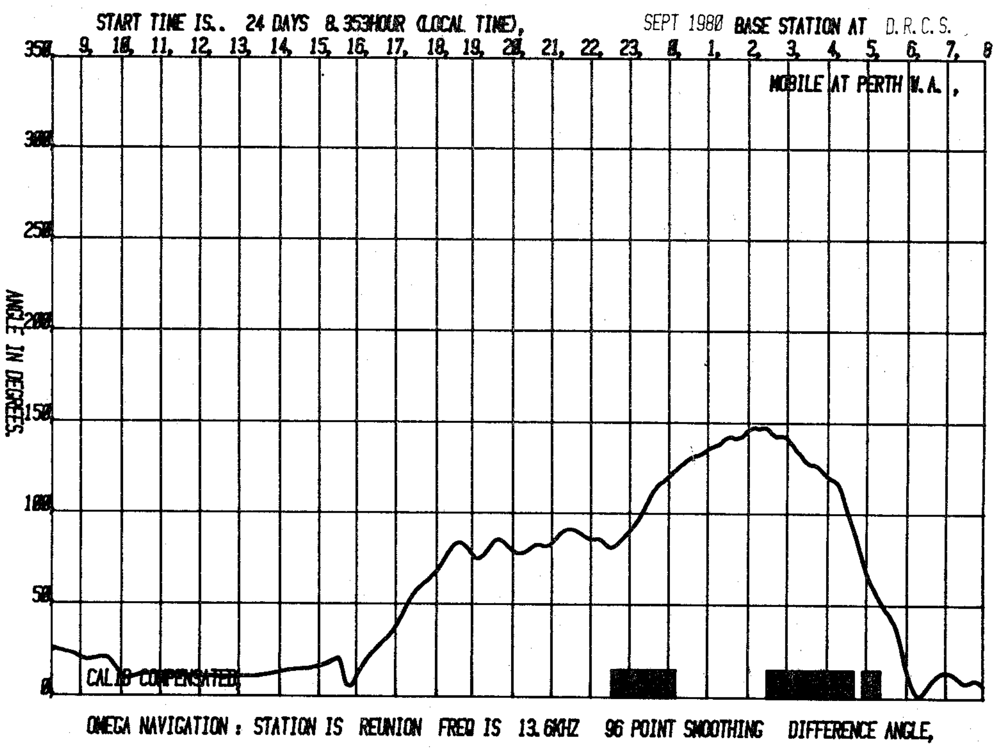


Figure 76. Angular difference (75)-(74)

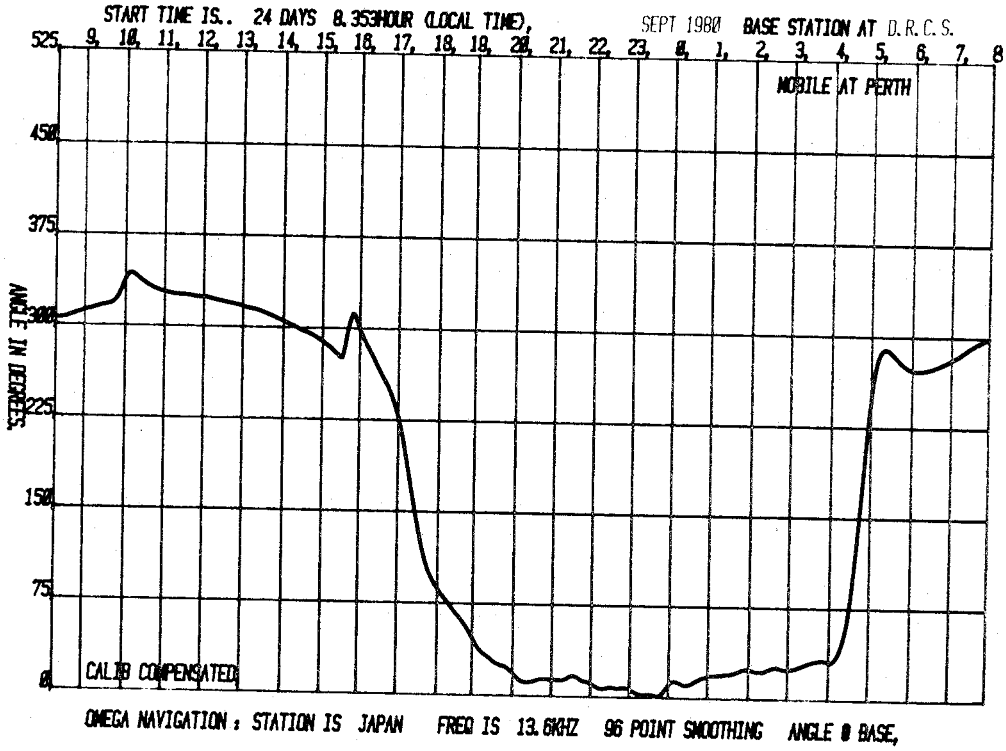


Figure 77. Diurnal phase of Japan in Adelaide on 13.6 kHz 24/25 September

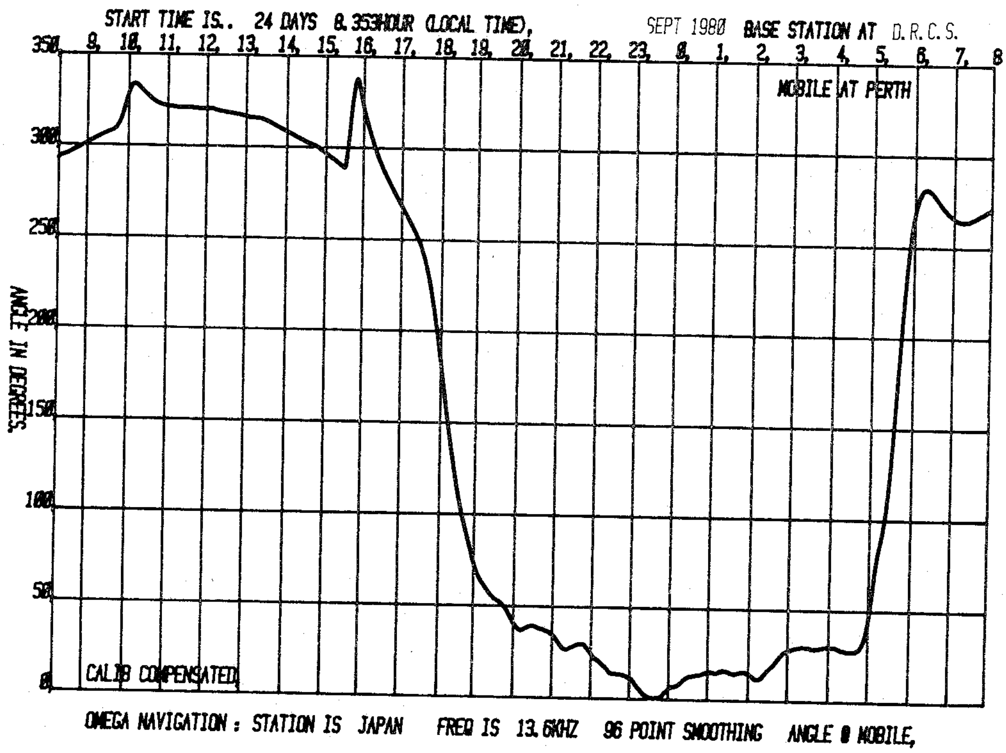


Figure 78. Diurnal phase of Japan in Perth on 13.6 kHz 24/25 September

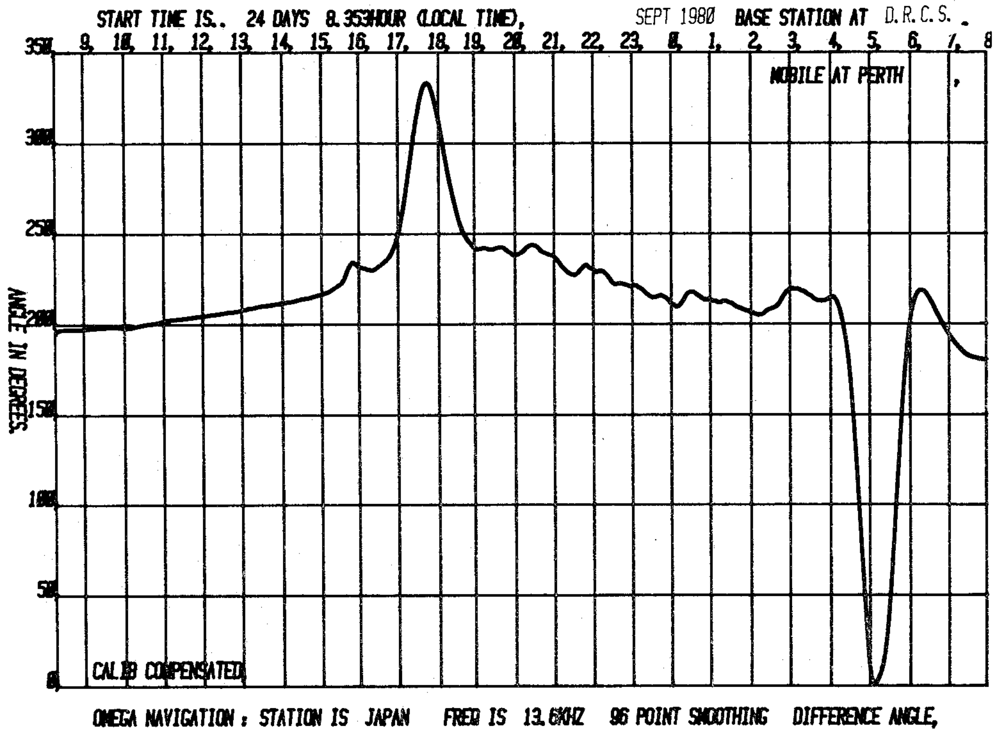


Figure 79. Angular difference (78)-(77)

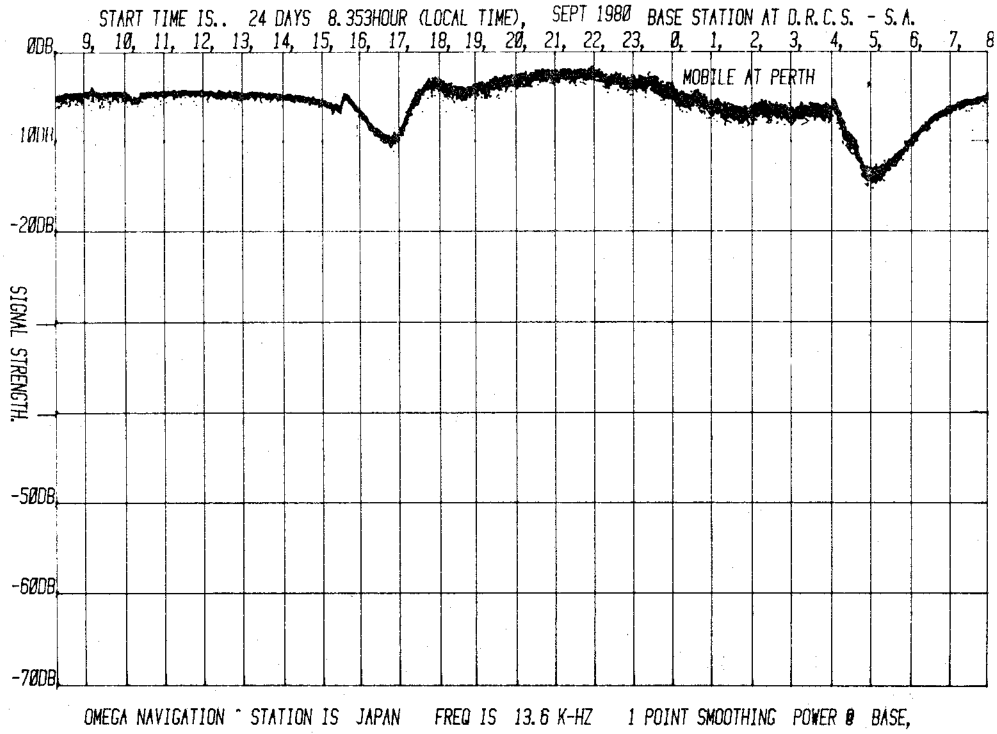


Figure 80. Signal level of Japan in Adelaide on 13.6 kHz 24/25 September

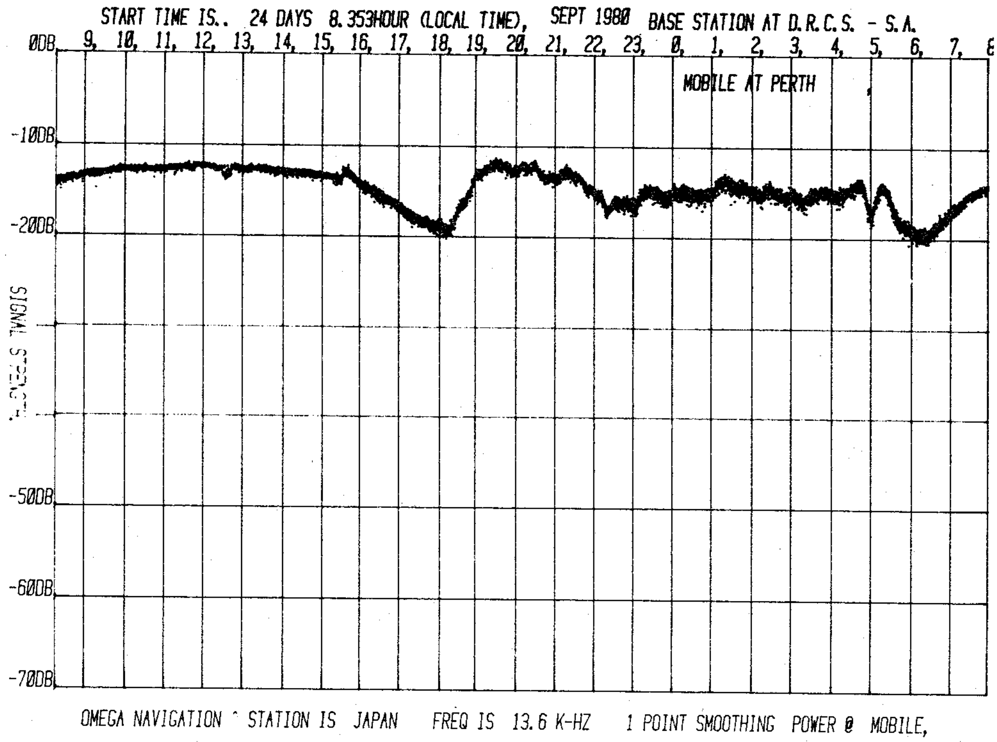


Figure 81. Signal level of Japan in Perth on 13.6 kHz 24/25 September

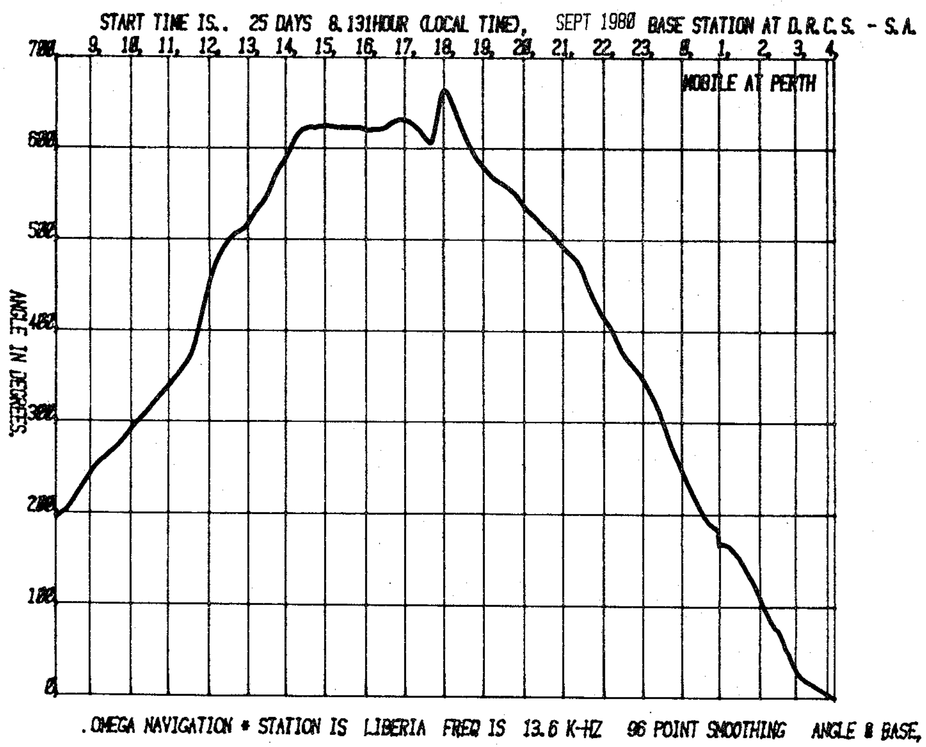


Figure 82. Diurnal phase of Liberia in Adelaide on 13.6 kHz 25/26 September

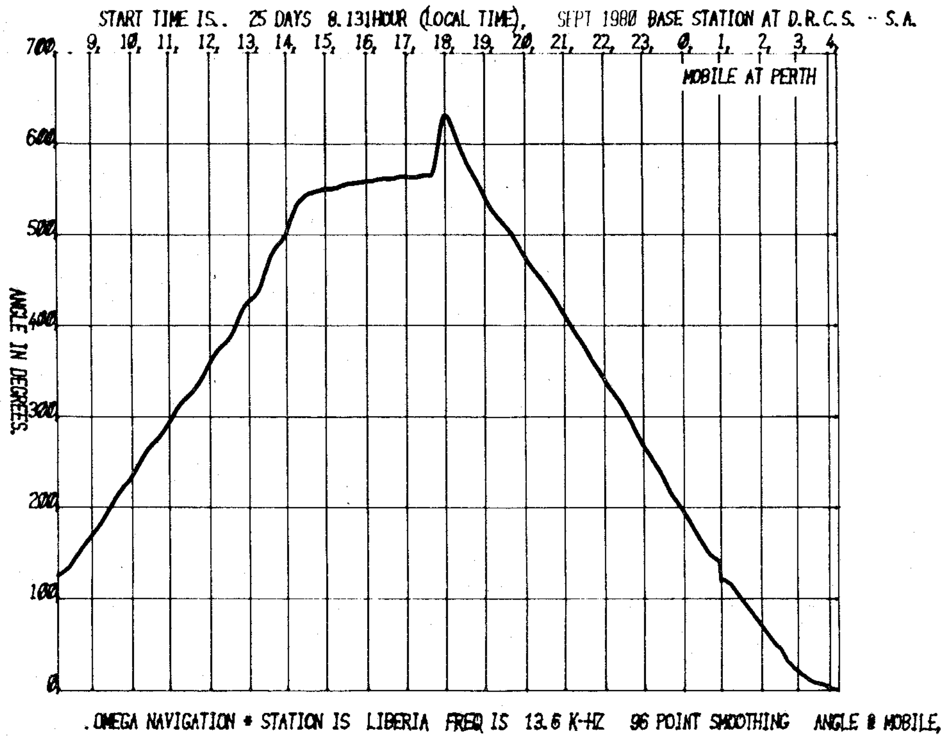


Figure 83. Diurnal phase of Liberia in Perth on 13.6 kHz 25/26 September

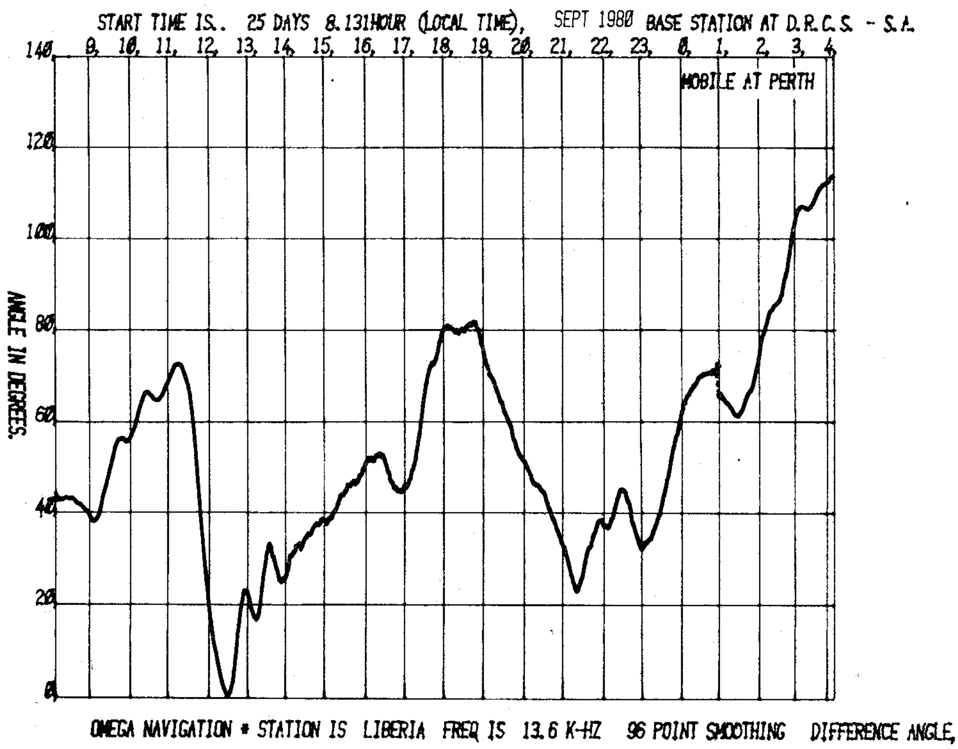


Figure 84. Angular difference (83)-(82)

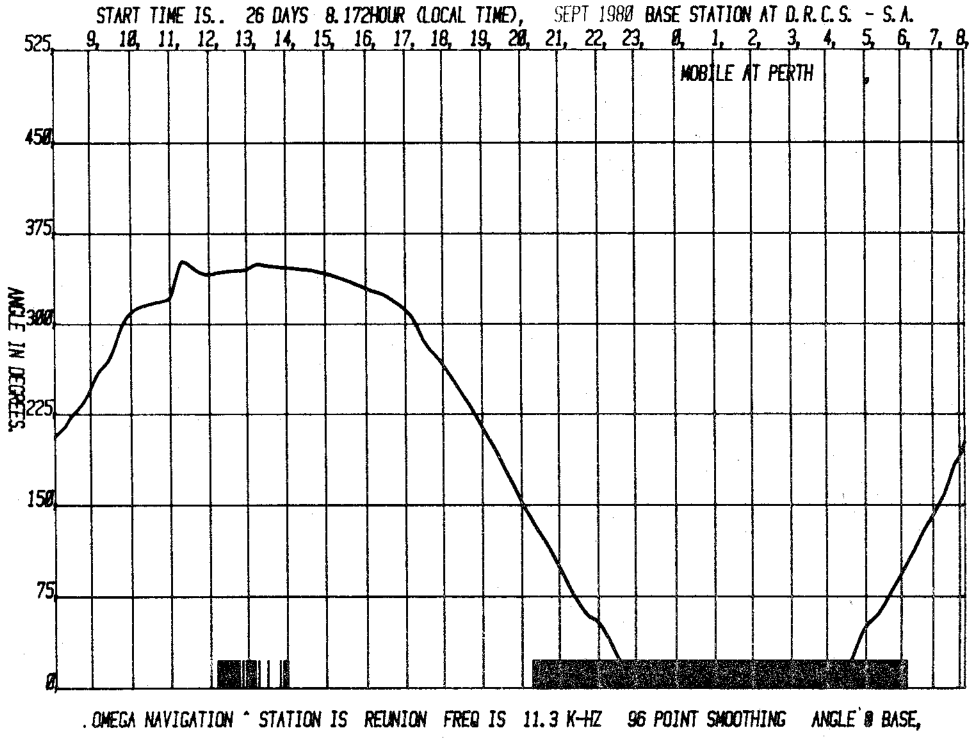


Figure 85. Diurnal phase of Reunion in Adelaide on 11.3 kHz 26/27 September

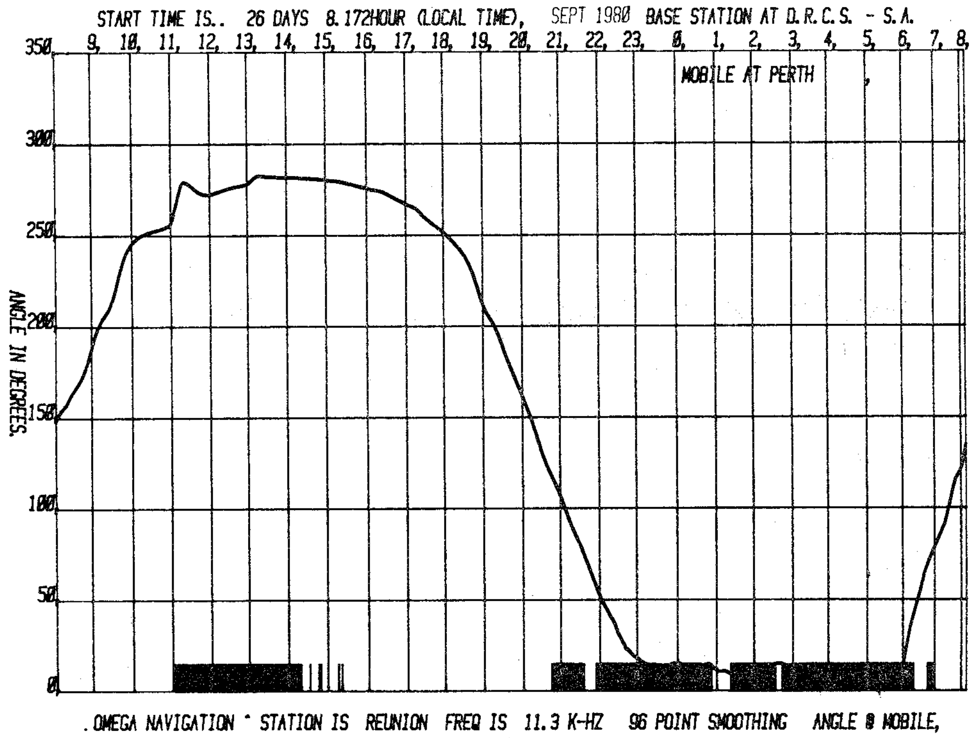


Figure 86. Diurnal phase of Reunion in Perth on 11.3 kHz 26/27 September

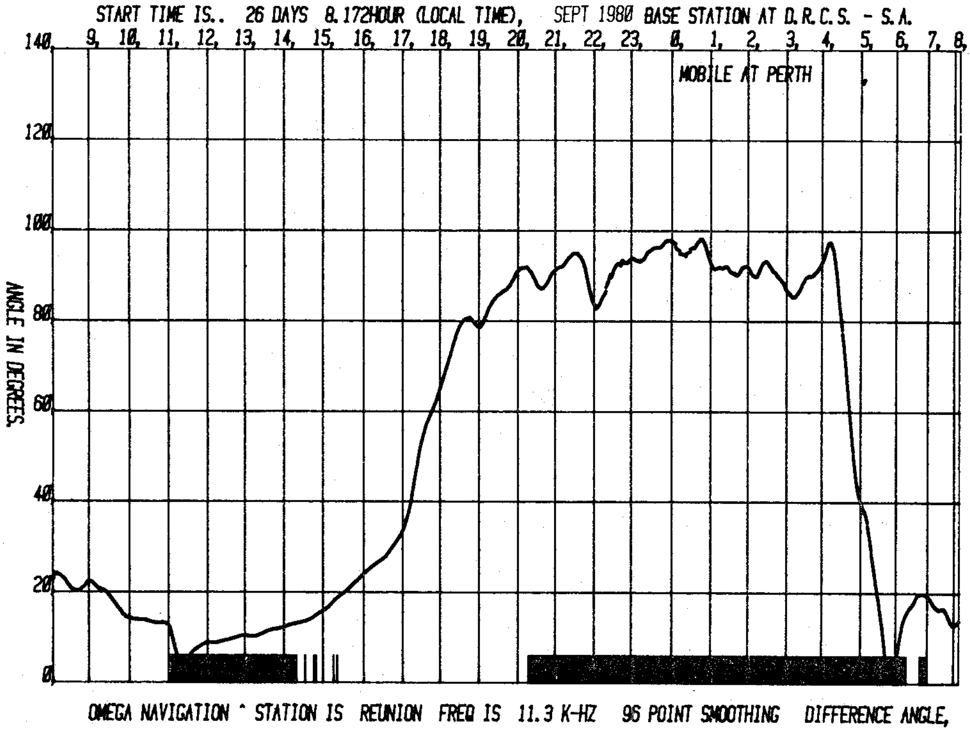


Figure 87. Angular difference (86)-(85)

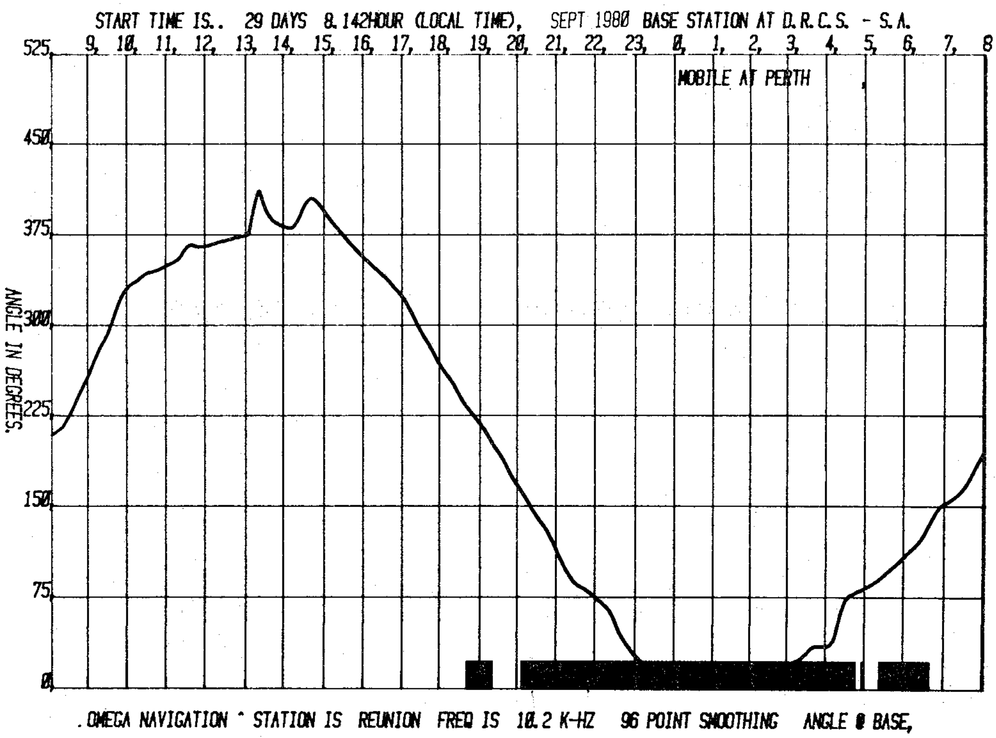


Figure 88. Diurnal phase of Reunion in Adelaide on 10.2 kHz 29/30 September

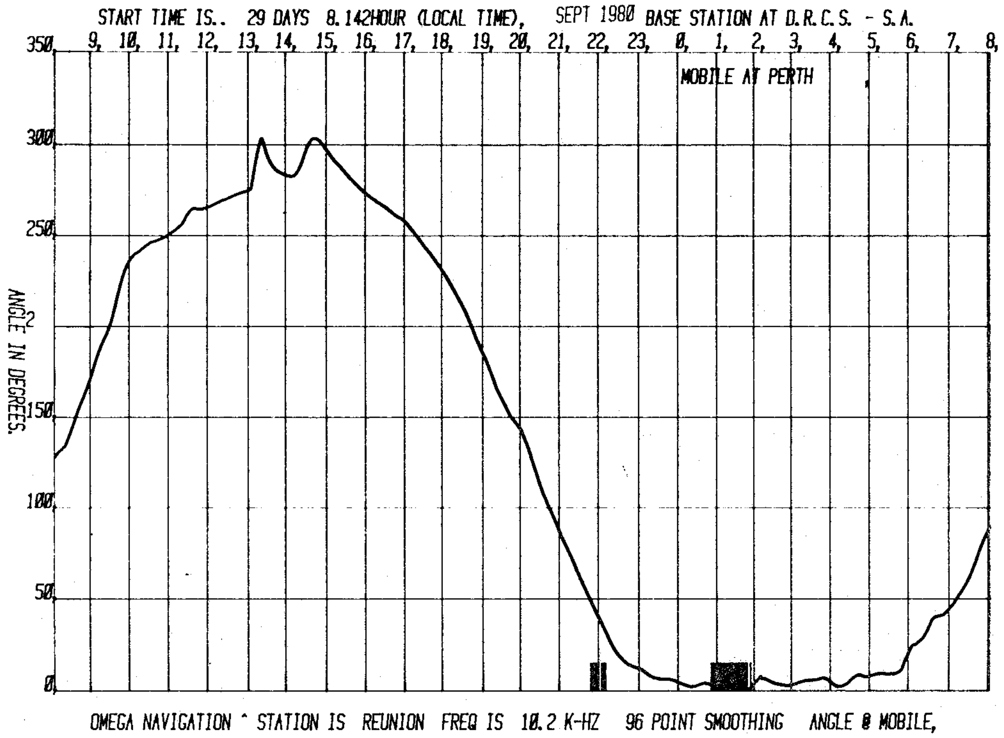


Figure 89. Diurnal phase of Reunion in Perth on 10.2 kHz 29/30 September

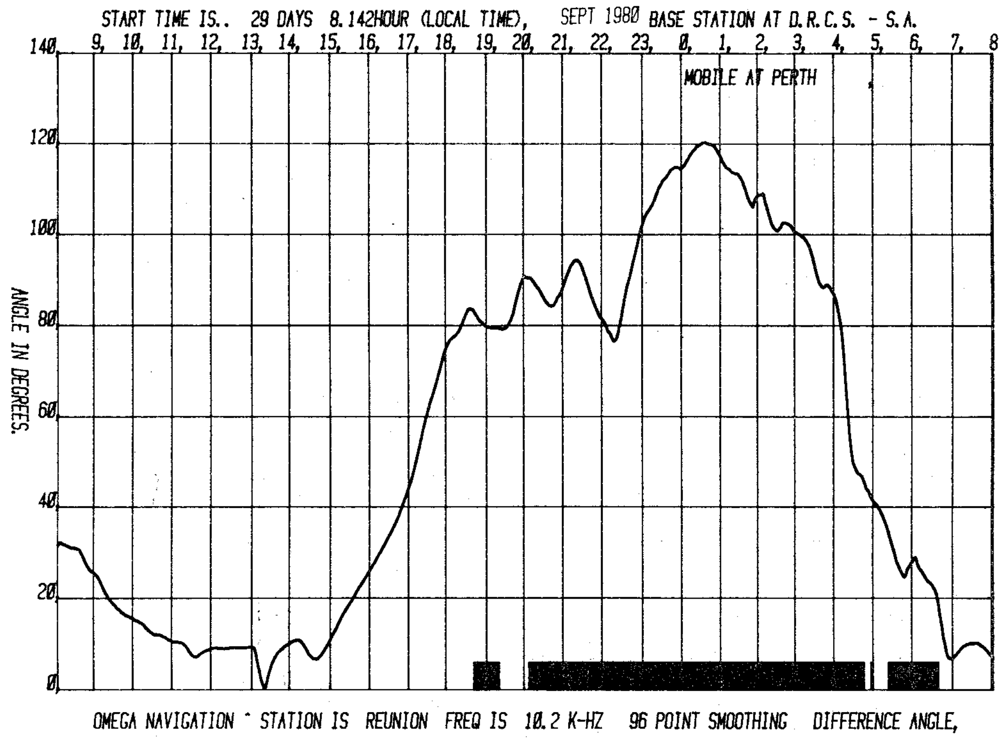


Figure 90. Angular difference (89)-(88)

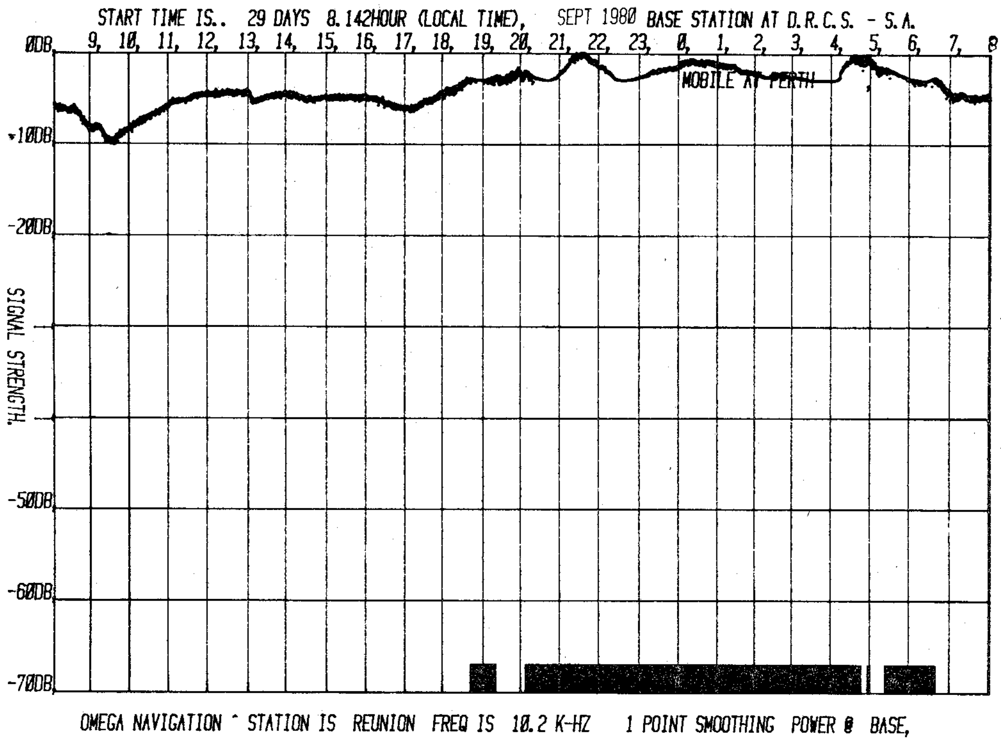


Figure 91. Signal level of Reunion in Adelaide on 10.2 kHz 29/30 September

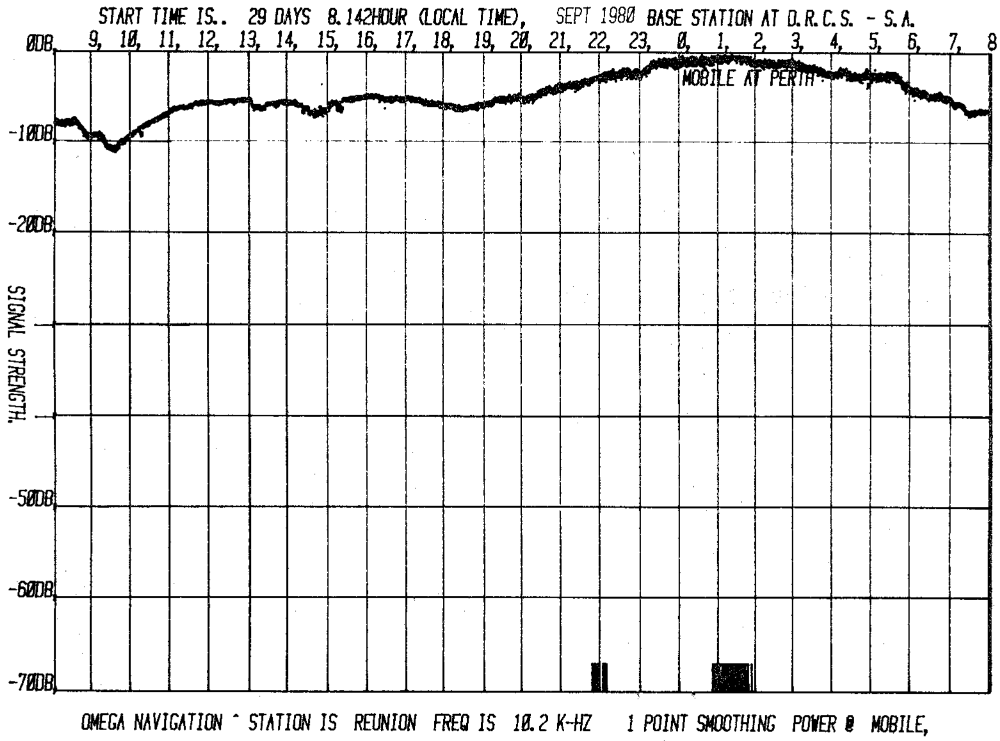


Figure 92. Signal level of Reunion in Perth on 10.2 kHz 29/30 September

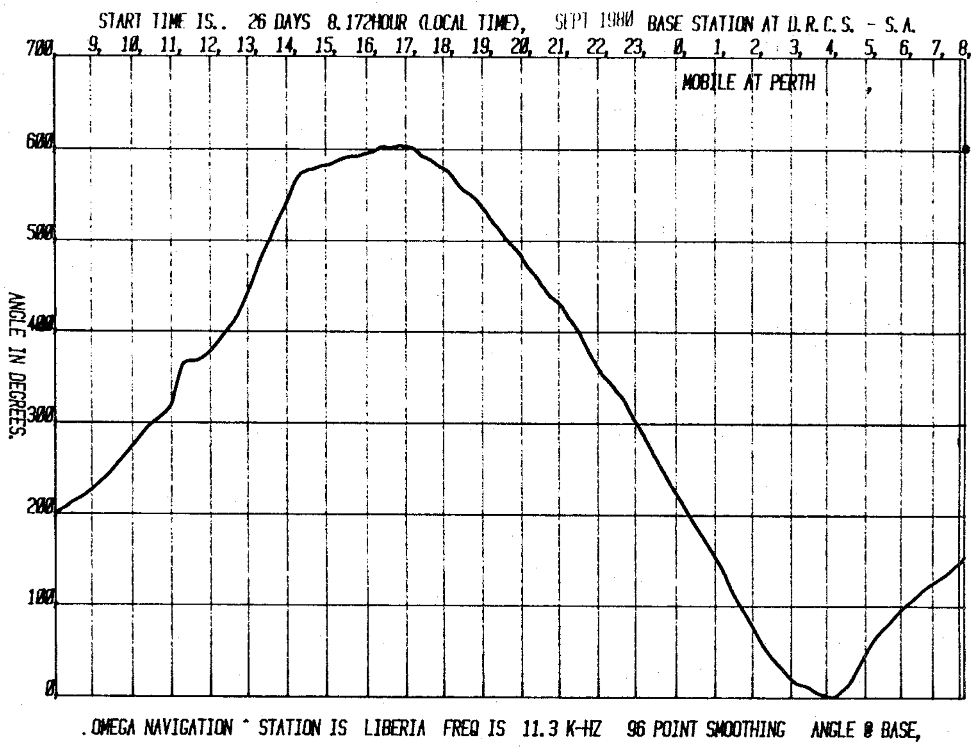


Figure 93. Diurnal phase of Liberia in Adelaide on 11.3 kHz 26/27 September

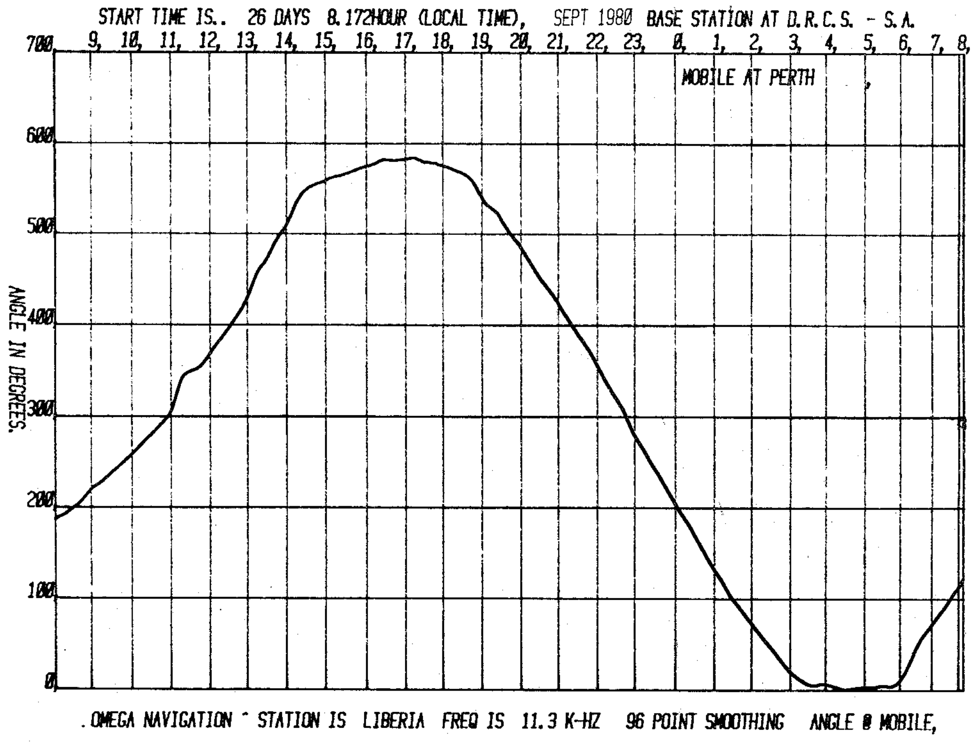


Figure 94. Diurnal phase of Liberia in Perth on 11.3 kHz 26/27 September

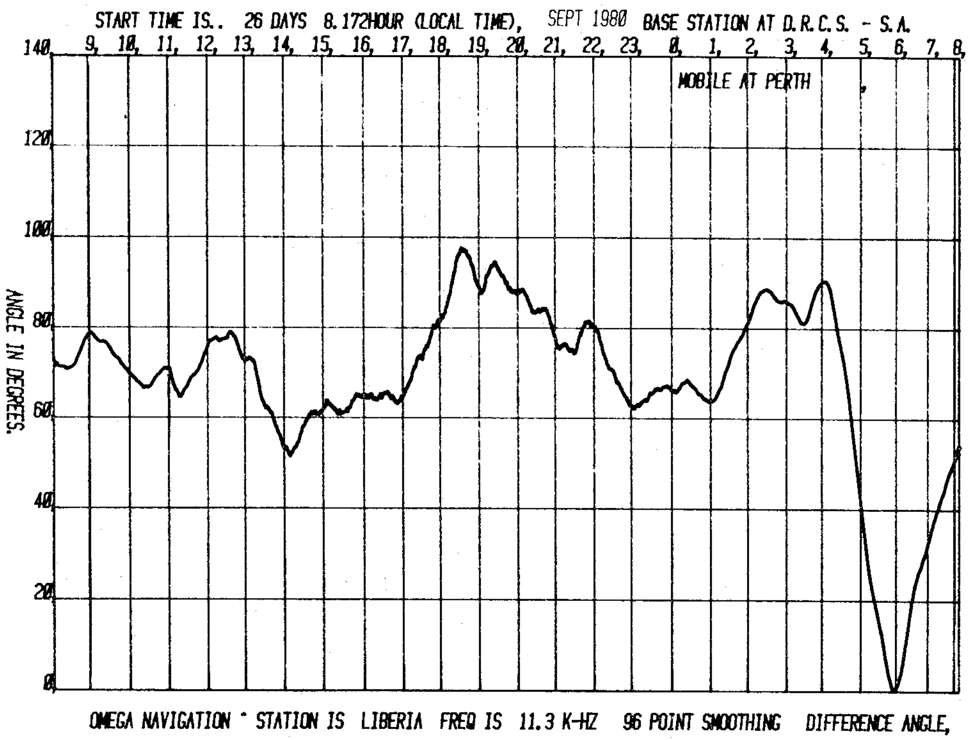


Figure 95. Angular difference (94)-(93)

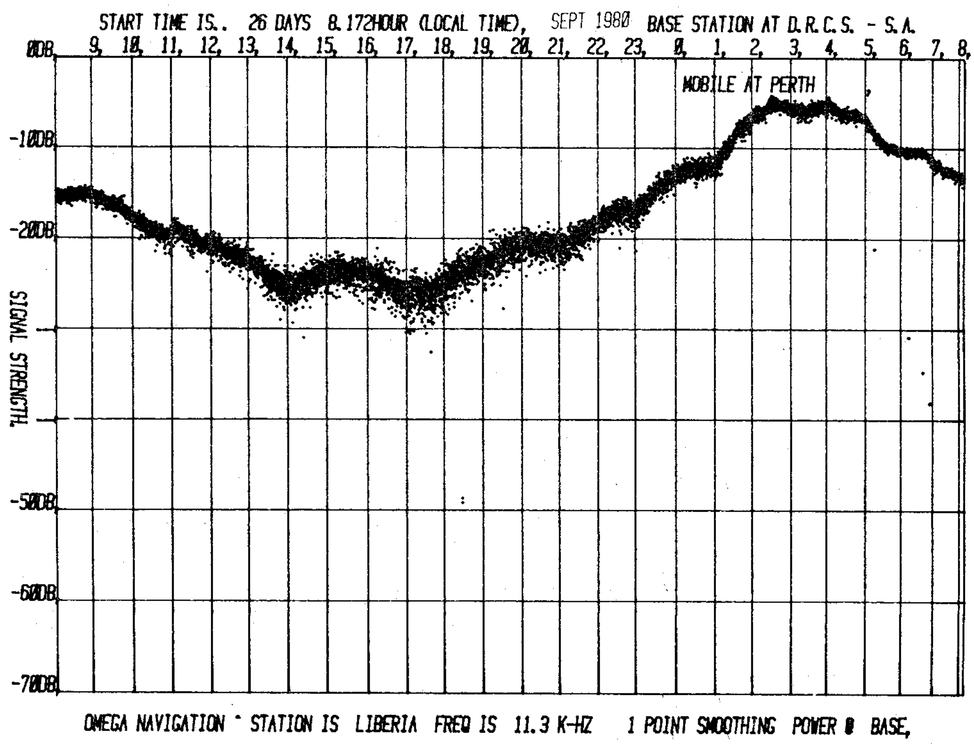


Figure 96. Signal level of Liberia in Adelaide on 11.3 kHz 26/27 September

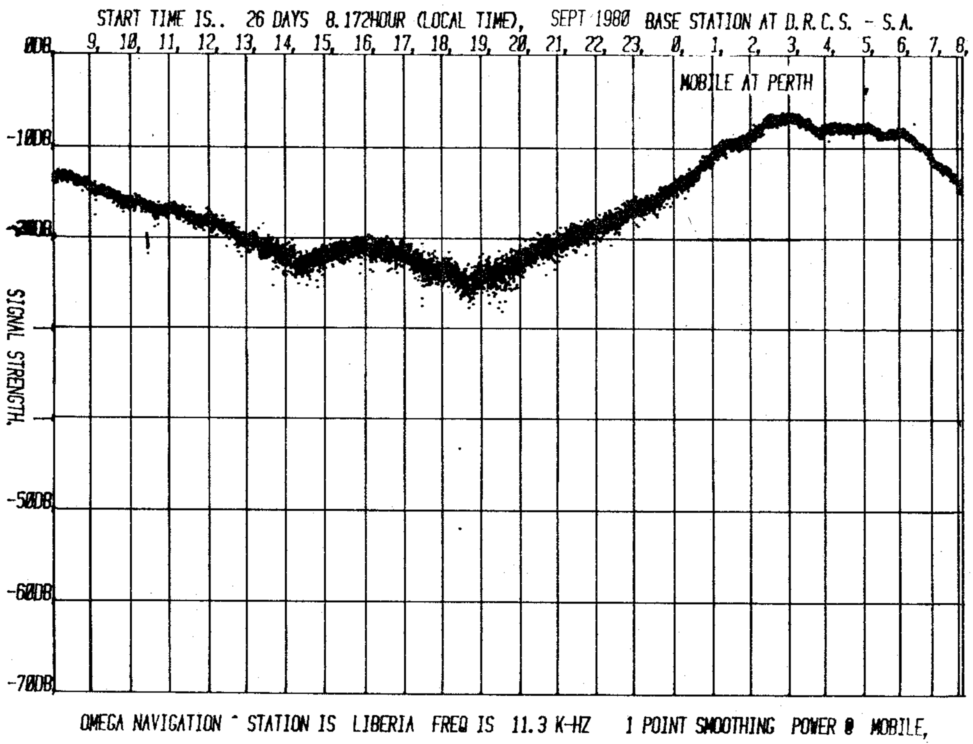


Figure 97. Signal level of Liberia in Perth on 11.3 kHz 26/27 September

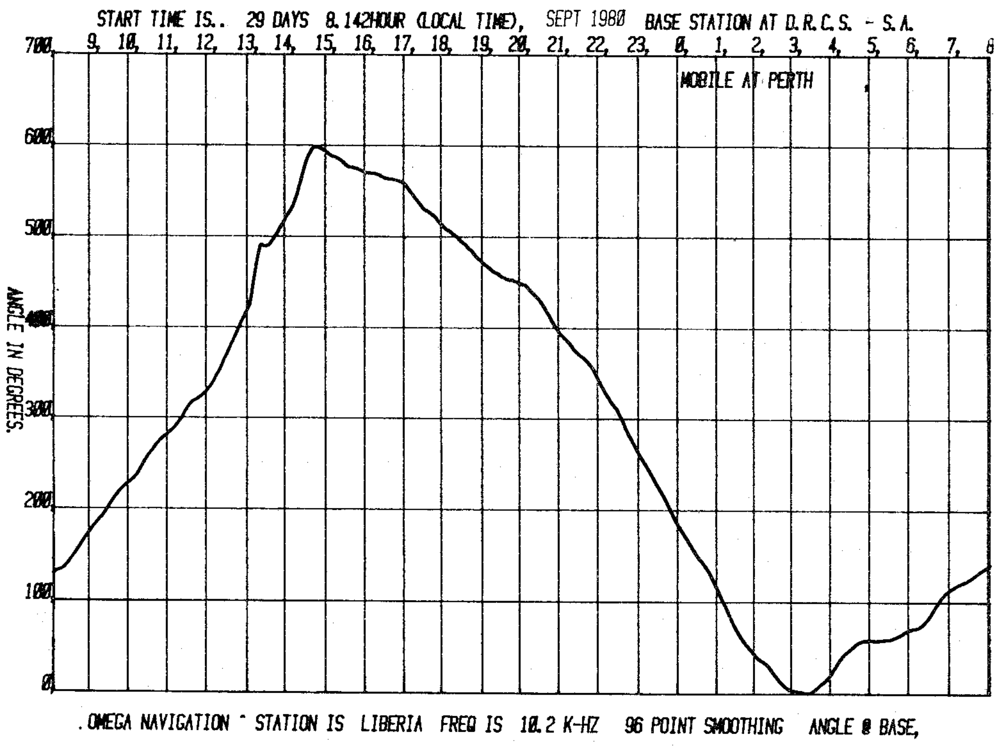


Figure 98. Diurnal phase of Liberia in Adelaide on 10.2 kHz on 29/30 September

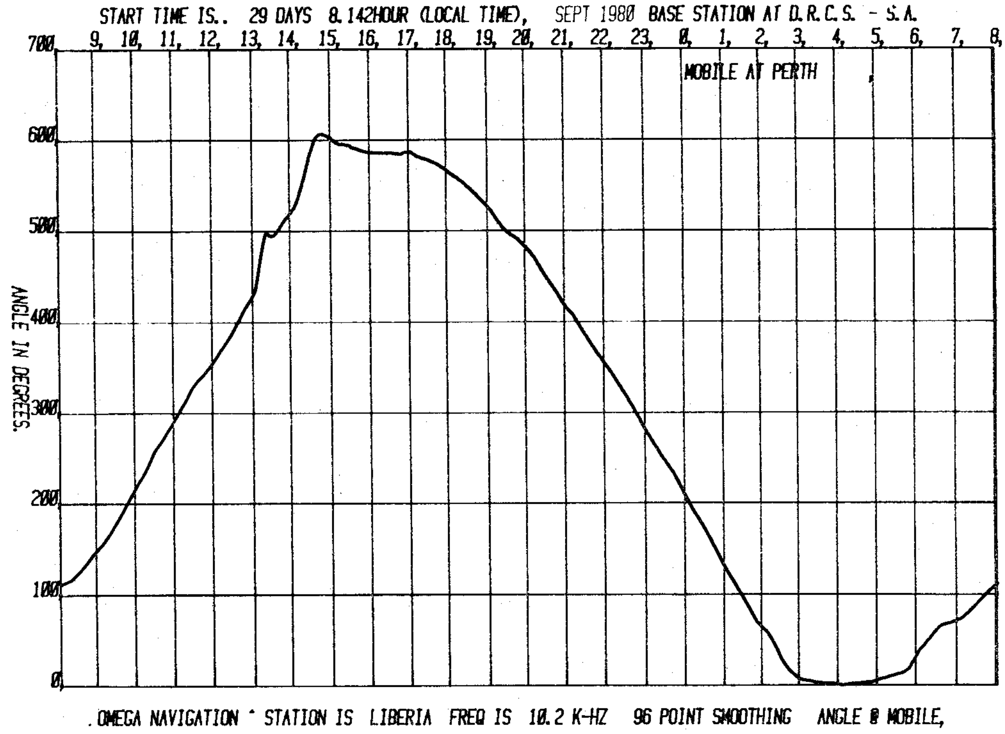


Figure 99. Diurnal phase of Liberia in Perth on 10.2 kHz 29/30 September

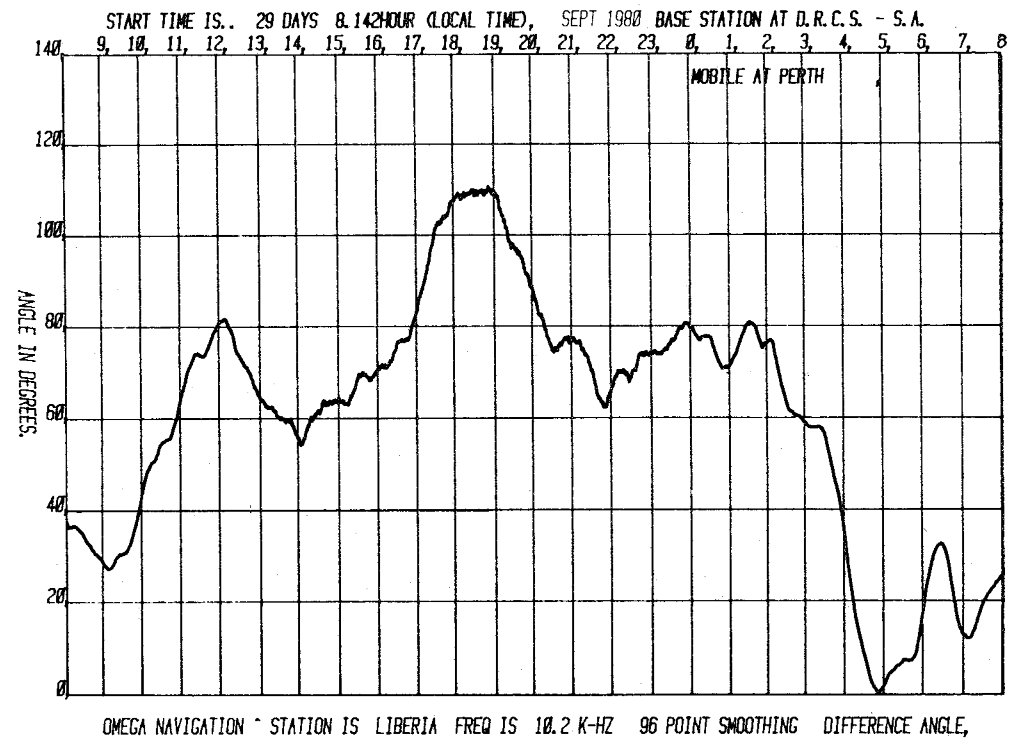


Figure 100. Angular difference (99)-(98)

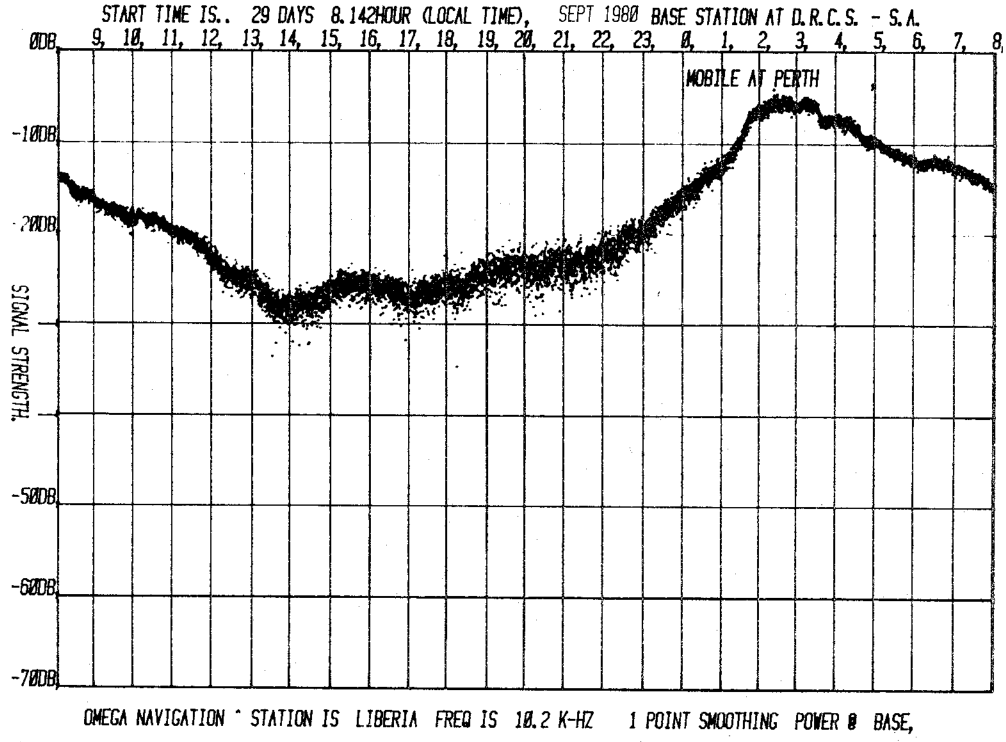


Figure 101. Signal level of Liberia in Adelaide on 10.2 kHz 29/30 September

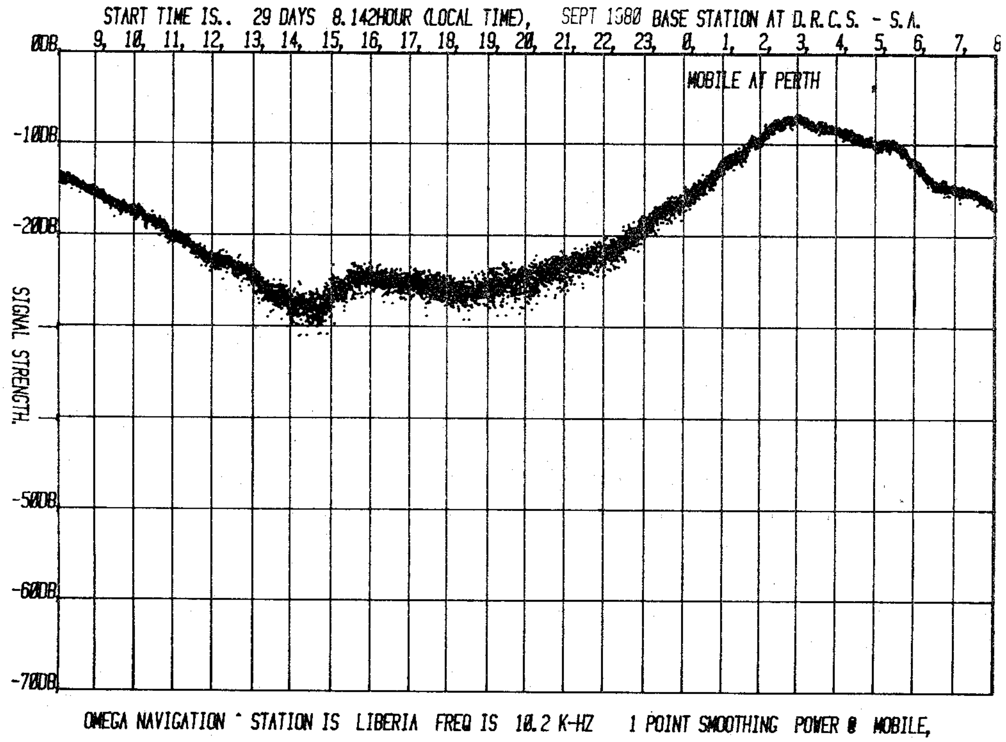


Figure 102. Signal level of Liberia in Perth on 10.2 kHz 29/30 September

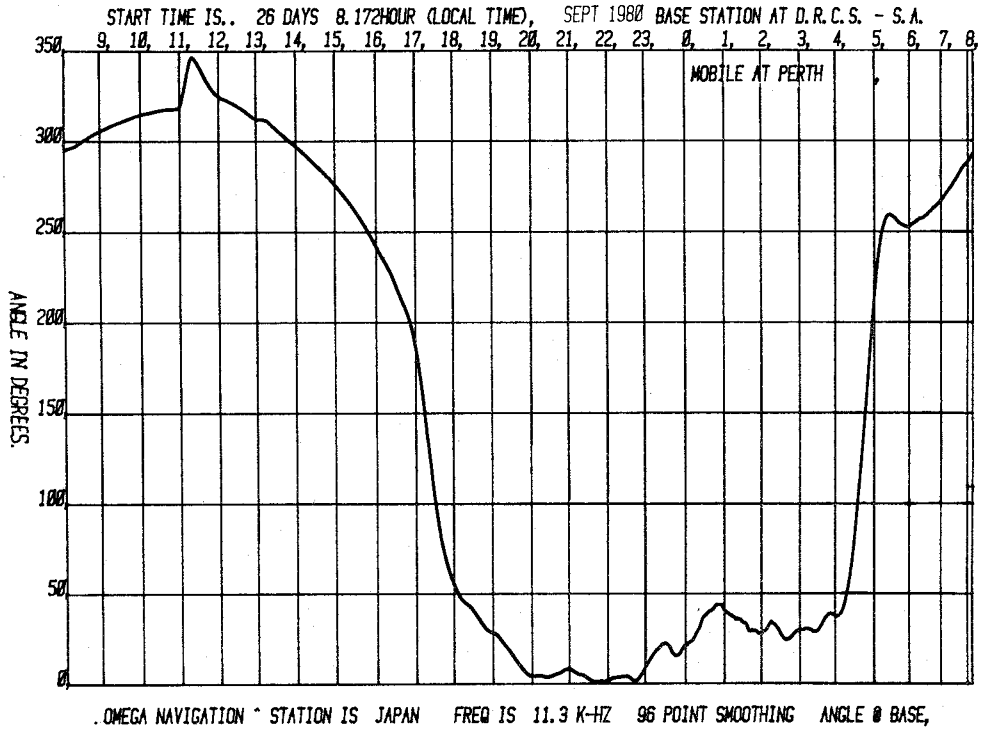


Figure 103. Diurnal phase of Japan in Adelaide on 11.3 kHz 26/27 September

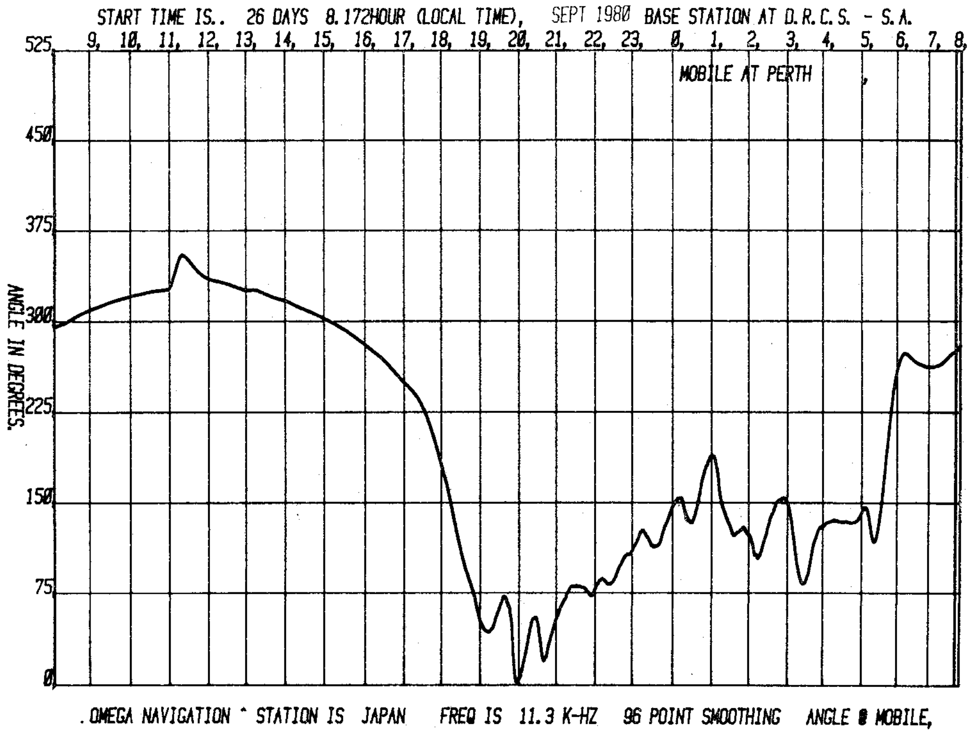


Figure 104. Diurnal phase of Japan in Perth on 11.3 kHz 26/27 September

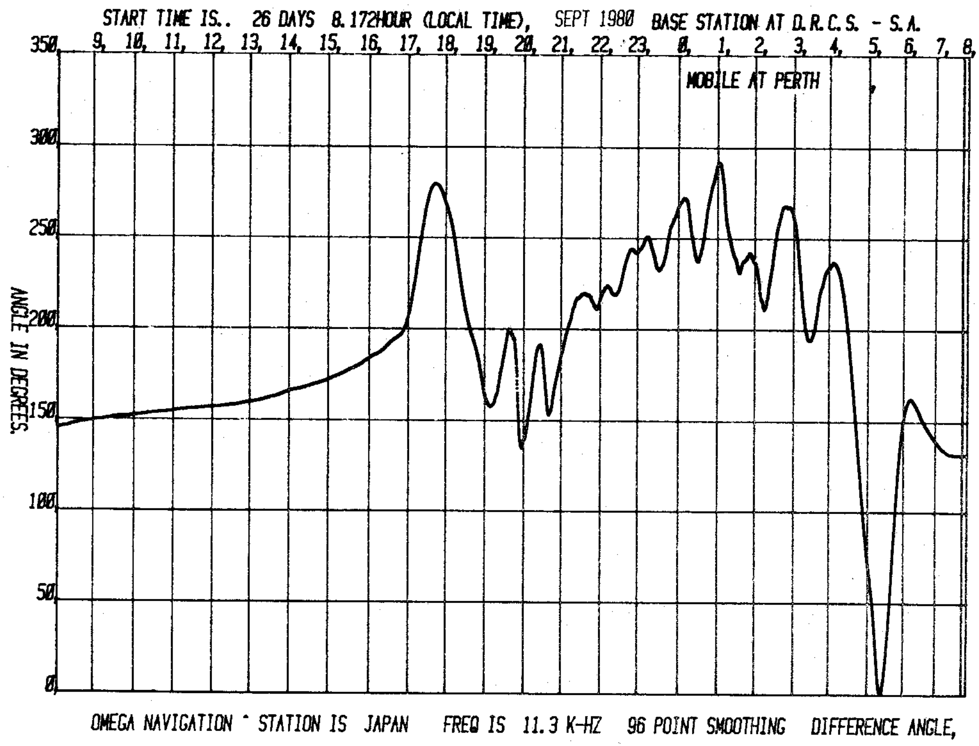


Figure 105. Angular difference (104)-(103)

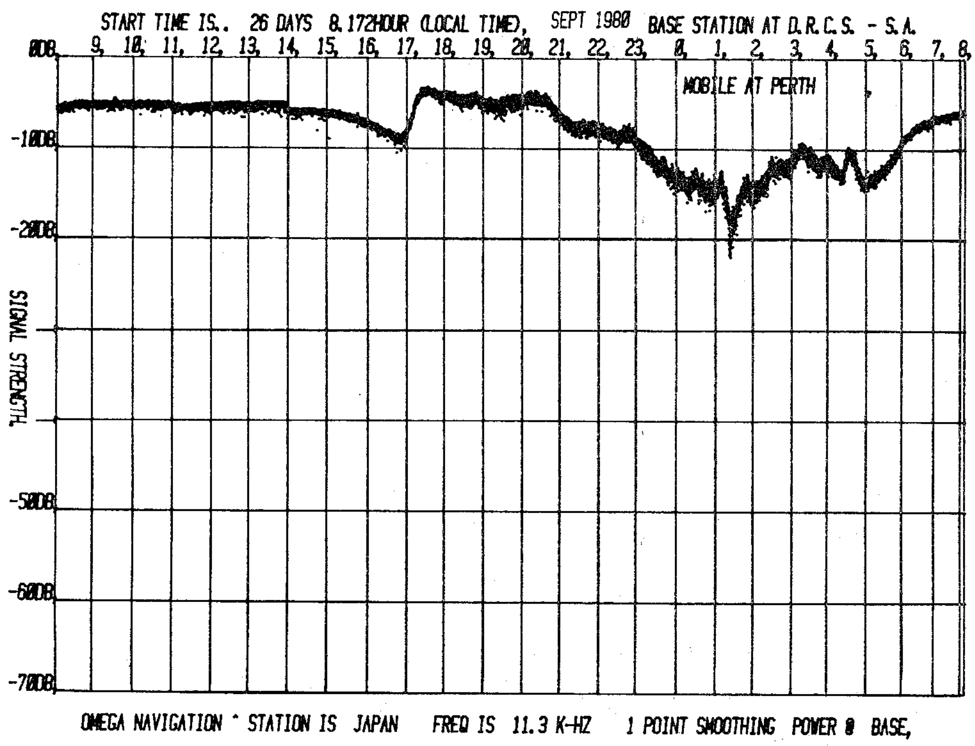


Figure 106. Signal level of Japan in Adelaide on 11.3 kHz 26/27 September

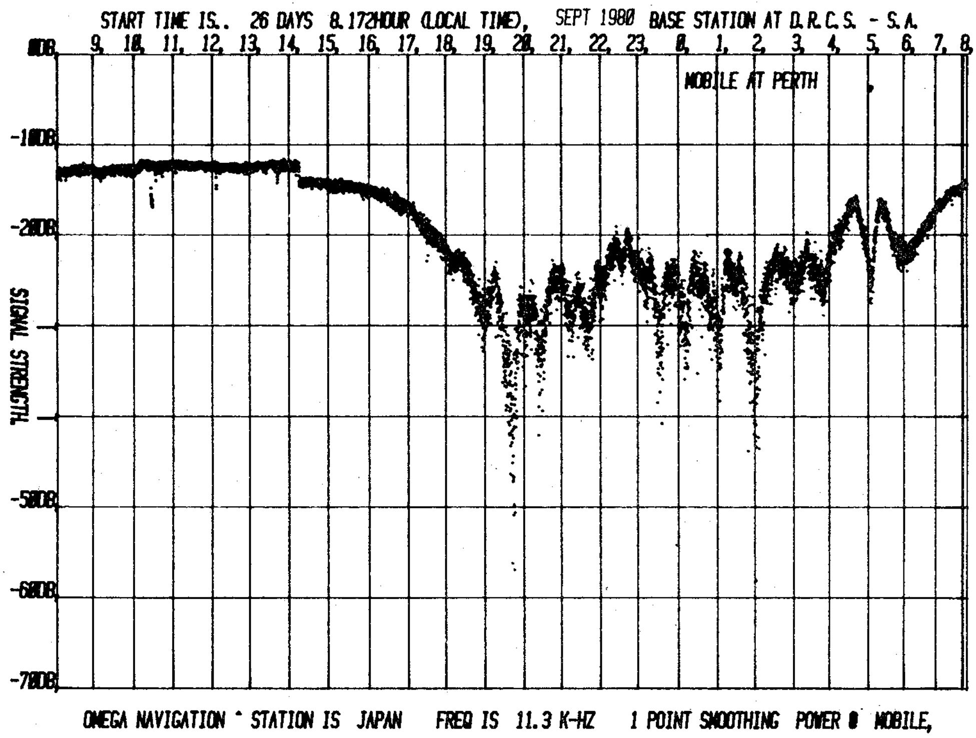


Figure 107. Signal level of Japan in Perth on 11.3 kHz 26/27 September

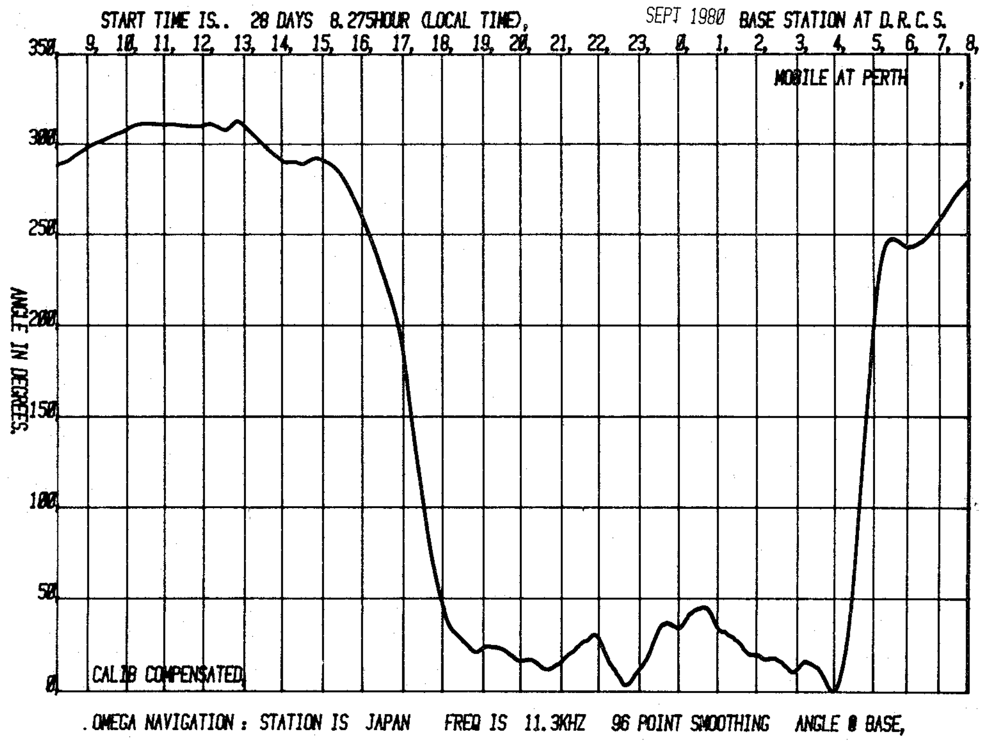


Figure 108. Diurnal phase of Japan in Adelaide on 11.3 kHz 28/29 September

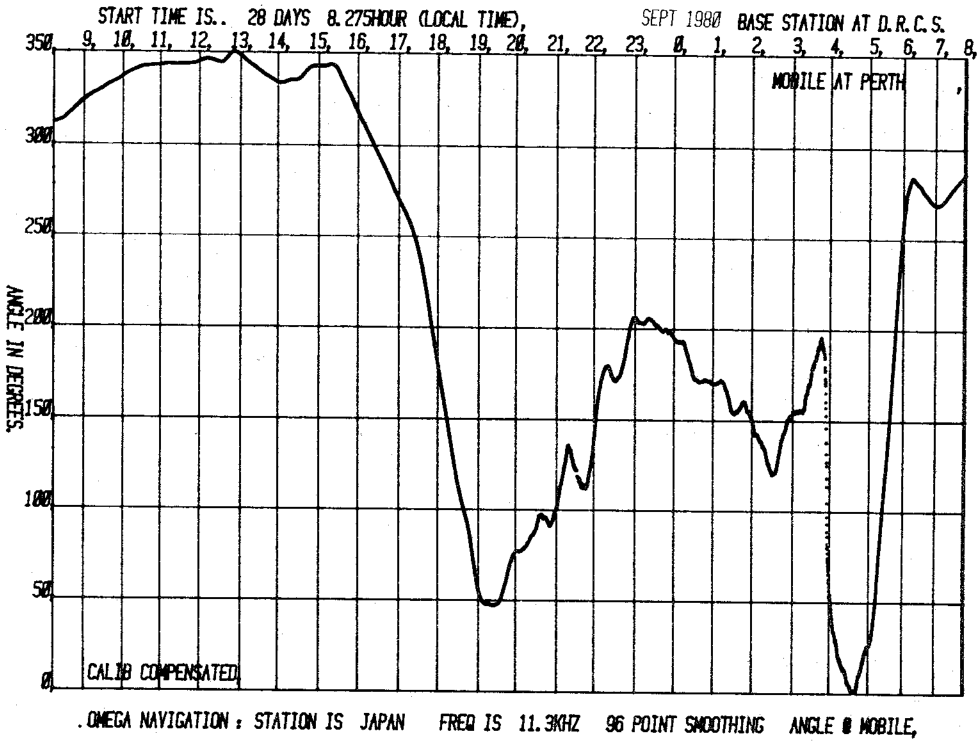


Figure 109. Diurnal phase of Japan in Perth on 11.3 kHz 28/29 September

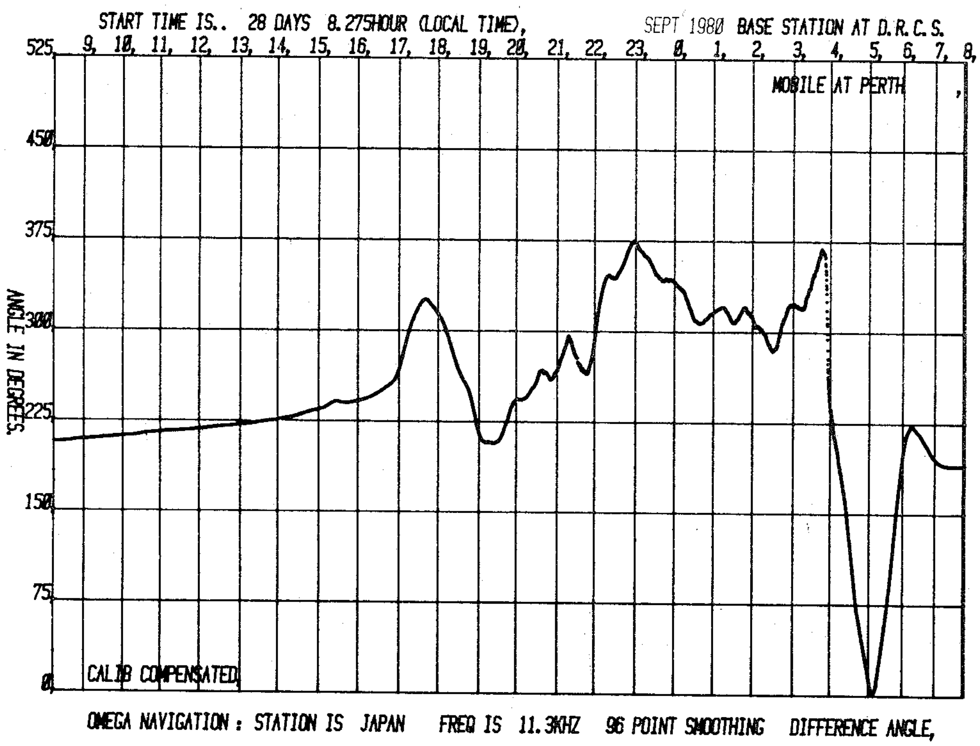


Figure 110. Angular difference (109)-(108)

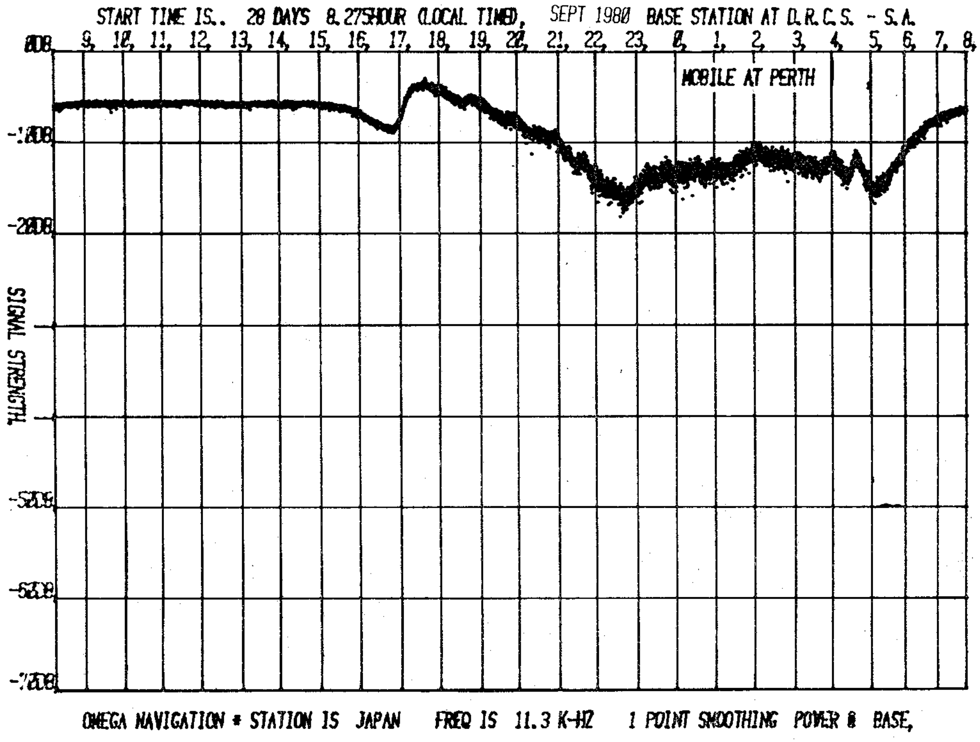


Figure 111. Signal level of Japan in Adelaide on 11.3 kHz 28/29 September

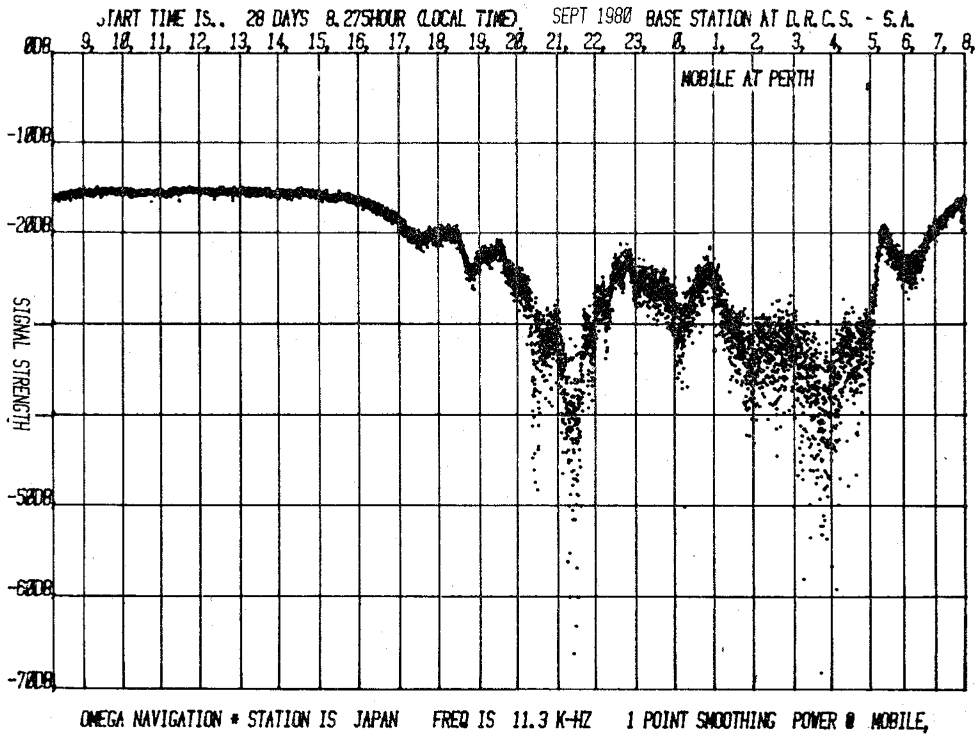


Figure 112. Signal level of Japan in Perth on 11.3 kHz 28/29 September

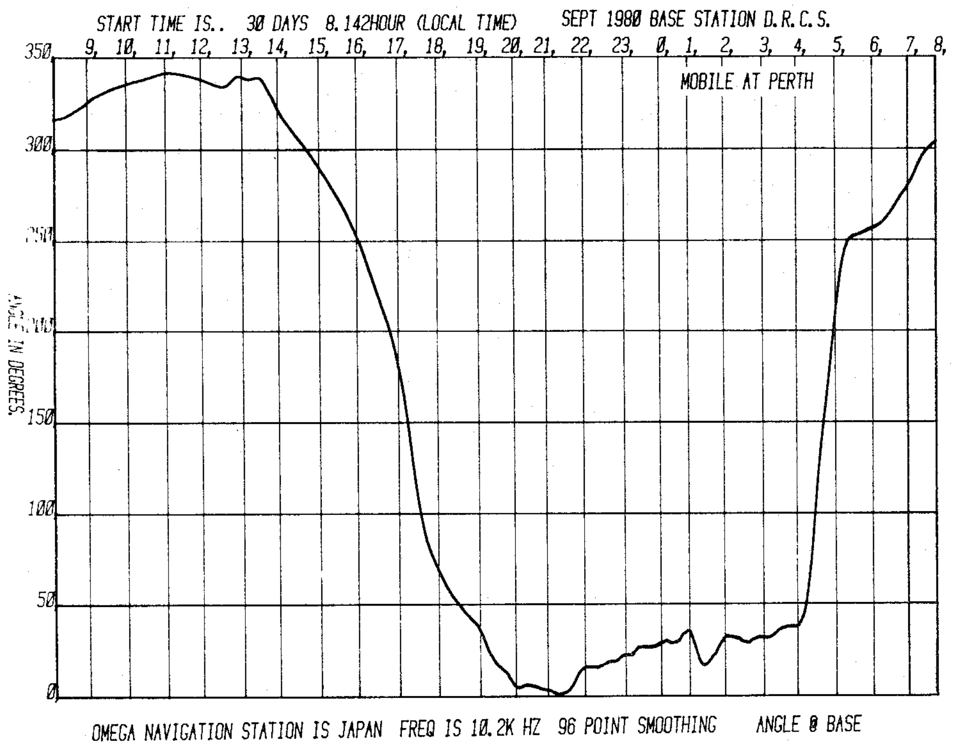


Figure 113. Diurnal phase of Japan in Adelaide on 10.2 kHz 30 Sept/1 Oct

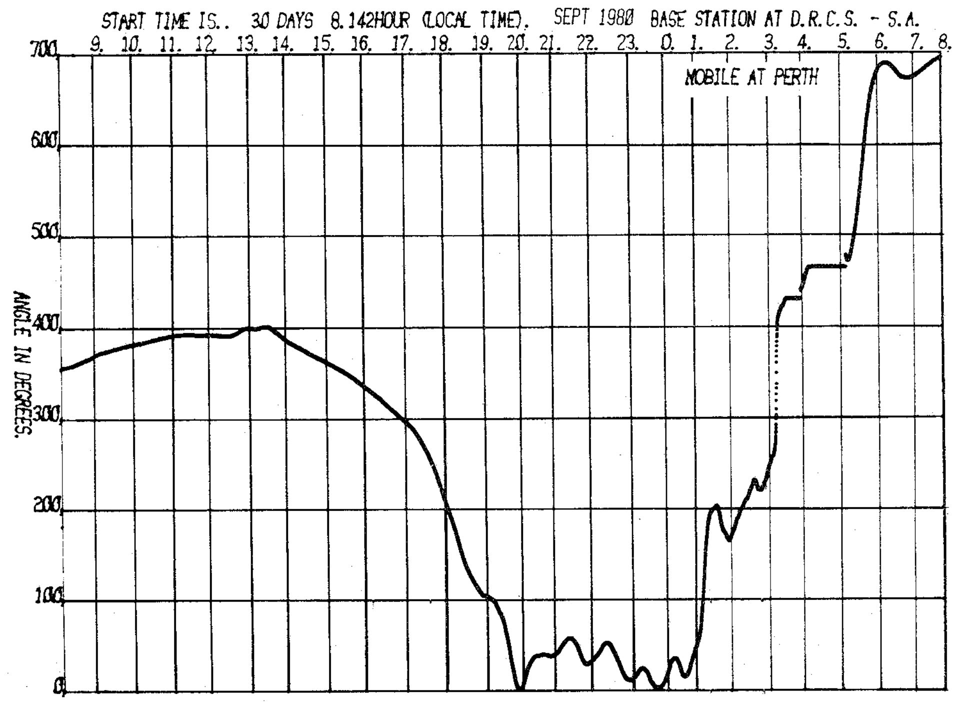


Figure 114. Diurnal phase of Japan in Perth on 10.2 kHz 30 Sept/1 Oct

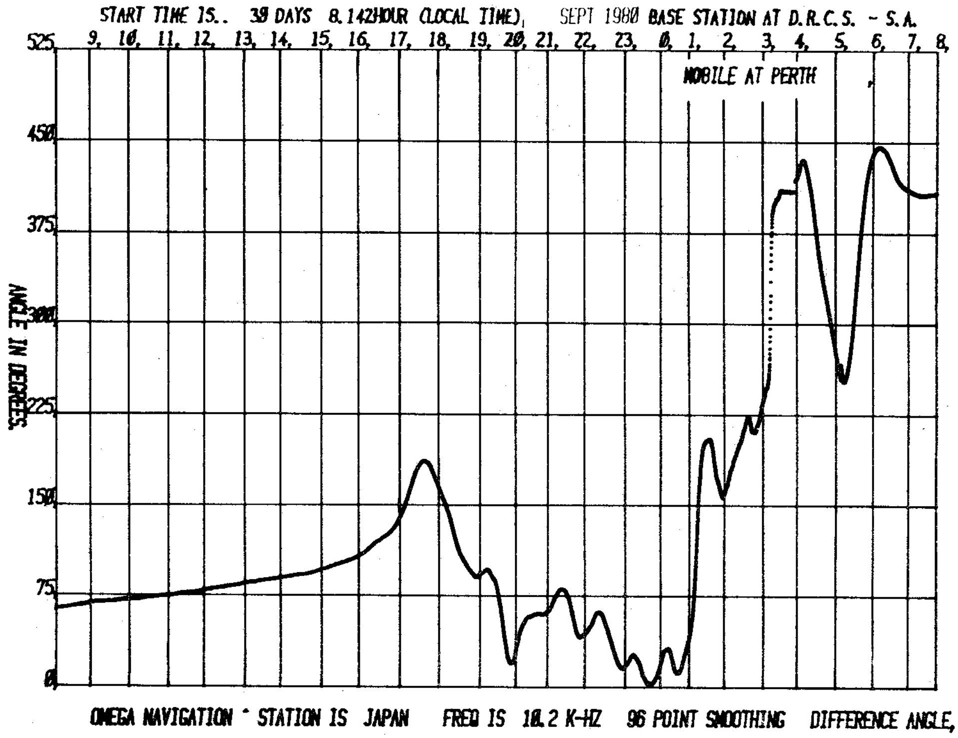


Figure 115. Angular difference (114)-(113)

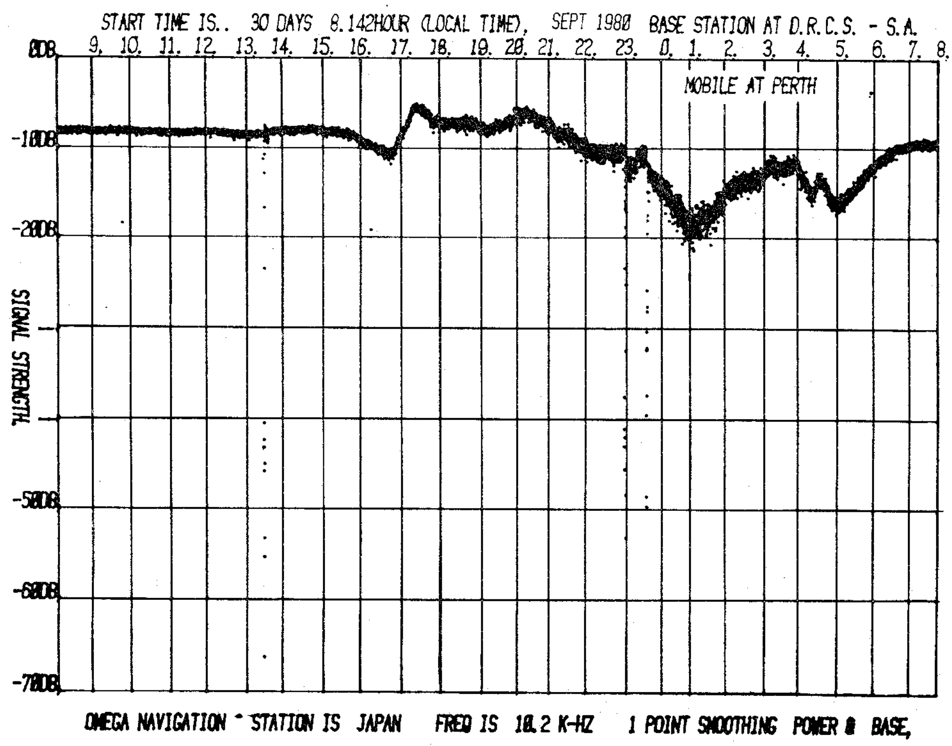


Figure 116. Signal level of Japan in Adelaide on 10.2 kHz 30 Sept/1 Oct

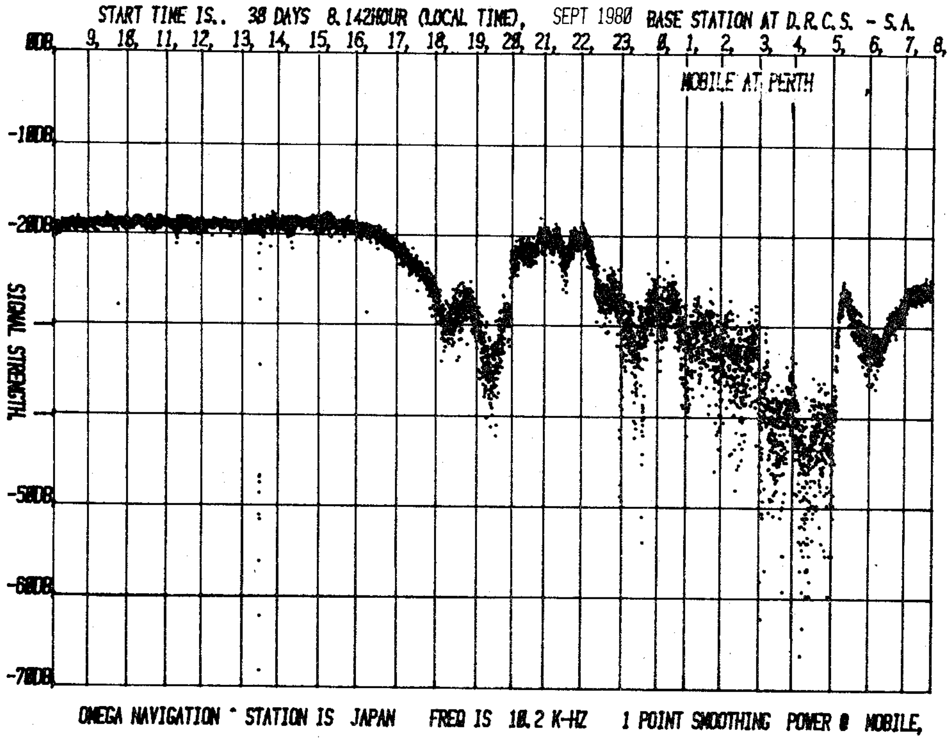


Figure 117. Signal level of Japan in Perth on 10.2 kHz 30 Sept/1 Oct

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13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

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14 DESCRIPTORS:

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Omega navigation

b. Non-Thesaurus Terms

Land navigation
Pilbara
Differential Omega
VLF navigation

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16 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

(U) Field trials were carried out in July/August 1980 to test the efficacy of Differential Omega for land navigation in the Pilbara region of Western Australia. To this end a base station was set up in Onslow and movements undertaken between the Onslow trig. station and similar survey marks at ranges of up to 400 km. This Technical Report describes the nature of the exercise and discusses the results obtained.

(U) Additionally, the diurnal phases of several Omega transmissions were recorded simultaneously in Perth and Adelaide during the return of the equipment to Salisbury. These records are subjected to a brief examination.

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